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INTRODUCTORY.

THE MEDICAL DEPARTMENT OF THE ROYAL NAVY.

IN the Royal Navy, where service in times of peace approximates so closely to the conditions in war, the organization of the Medical Department, in common with that of the other permanent branches, suffers no radical change when hostilities are declared. Such re-arrangements and extensions as occur have been rehearsed to a degree sufficient to test all the machinery required for a rapid mobilization to full war strength. Beyond the redistribution of a limited number of active service medical ranks and ratings, the admission of reservists, temporary service auxiliaries, and volunteers, and the extension of hospital accommodation, there is no disturbance of existing arrangements. The same organization which augments the personnel for the grand manœuvres of peace time is employed on occasions of war. The Medical Service required for new units and new formations arising during the progress of hostilities, such as the battalions of the Royal Naval Division and the Armoured Car and other detachments serving ashore, is but an extension of that supplying the Royal Marines and the Royal Naval Air Service which is permanently under Admiralty control; while the arrangements for the transport of wounded are but expansions of the system of collecting naval invalids and hospital cases from ports and fleets by hospital ships, a system that has been in existence for many years. The provision of hospital trains for the distribution of wounded to the naval hospitals, and the appointment of medical transport officers to control this service, is practically the only part of the programme of transport that has not been rehearsed.

This easy transition from peace to war is in marked contrast to the violent dislocation and re-organization which of necessity attend the mobilization of large military expeditionary forces and the creation of huge armies from raw material. In the Navy, fortunately, the expansion, great as it is, has not proved overwhelming. The many hundreds of civil entries—surgeons, nursing-sisters, and sick-berth ratings—have been absorbed into its system

without upsetting the medical organization or diverting the regular medical staff from the duties for which they have been specially trained. In the naval hospitals, establishments, hospital ships, and in all large fighting ships, administration, responsibility for the care and attention of the sick and wounded, together with the greater part of the practical work—surgical, medical, bacteriological, etc.—remains under the immediate care of the regular medical officers. Fortunately, indeed: because, however skilled and capable a civilian may be, it takes many years of close association with the Navy to acquire that intimate knowledge of the Service and to develop to the fullest value those qualities required to mould the man to fill his part in that complex machine the modern battleship, or to perform with efficiency his share of the administrative work of a naval hospital.

To deal adequately with the surgical organization in the present naval war it would be necessary to describe the normal organization in more detail than space permits. It must suffice to limit the review to a consideration of certain special features, and to the focal point of interest—the naval surgeon himself, his general efficiency, and his ability to apply the resources of modern surgery to the benefit of the wounded sailor at the time of injury and after.

As a Health Officer of the Navy, the Surgeon—to give him his official title—has stood the test. Year by year the sick rate has steadily decreased. In this, the third year of war, the ratio in the Grand Fleet is but little more than one per cent. Many factors have combined to produce this immunity from sickness. The share of the medical officer in the achievement is not to be overlooked. One is tempted to dilate upon so important a subject, and to contrast the present with past occasions of war which have kept large fleets in being: but in a journal devoted to surgery matters of hygiene are of subsidiary interest.

The Navy is proverbially a silent Service. The reticence of the medical branch accounts, perhaps, for the ignorance of the public concerning the naval medical officer, his duties, his opportunities, and his aspirations. With the exception of some admirable work in the study of tropical diseases, he is rarely to be found as a contributor in the pages of professional literature. Until the birth of the *Journal of the Royal Naval Medical Service* some two years ago, his written word has lain buried in official records and reports. It is no exaggeration to say that in the popular fancy he is still the 'cockpit' surgeon of Smollett's novels, rough, and over-ready to probe a wound or amputate a limb. That he should have opportunities for practising any but 'cockpit' surgery is unimagined by the general public. The humour of *Punch's* illustration of a sailor mildly expostulating that the surgeon has dragged him round the sick-bay with the dental forceps attached to his tongue instead of to his tooth, lies in the indulgent acceptance, by the patient and the public, of the operator's limitations.

We are often reminded that the lay medical profession is not more enlightened than the general public concerning the Naval Medical Service. Of some six hundred and fifty young men who, at their country's call, have joined the Navy as temporary surgeons, few had any conception of the nature of the Service they were entering. A medical officer of a fighting-ship was to them but a glorified variant of the 'qualified surgeon' of the passenger ship's advertisements. They learned with surprise that they were not to be drafted at once for service afloat. They found themselves appointed temporarily to one of several huge naval hospitals—institutions hitherto unheard of by them. They were to learn that these establishments are complete in every up-to-date detail; that in the several departments, medical, surgical, *x*-ray, bacteriological, venereal, zymotic, etc., the work is carried on, and for years has been carried on, with that eager aim to obtain the highest efficiency which is traditional in the Naval Service. They were to learn that these departments are staffed and administered by naval surgeons who, with the exception of those of the higher ranks, are taking their turn at hospital work after a recent term of service afloat.

Here, in these self-contained hospitals naval surgeons perform daily many surgical operations. A total of nearly 5000 operations—exclusive of dental operations and salvarsan intravenous injections—were placed to the credit of the naval hospitals during the last year of peace, and all were performed by naval surgeons who had acquired their operative experience and skill while in the Service. Since the beginning of the war the number of operations has greatly increased.* The surgical work has been assisted by the consultant surgeons who have supplemented the senior ranks, and by temporary surgeons who have relieved many of the junior operators.

It may appear surprising that in peace time there should be such a large amount of surgical material in a service composed of picked men, the majority in the prime of life. It is to be noted that this material is drawn not only from the Service afloat, but also from the large naval establishments ashore, such as the Royal dockyards—where many thousands of workmen are employed in shipbuilding, etc.—from training schools, and, to a limited extent, from

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* During the year 1916 over 9000 surgical operations (exclusive of dental operations and intravenous injections) have been performed in the naval hospitals and hospital ships. Of this number over 800 were abdominal cases, including 627 cases of appendicitis and 55 of gastric or intestinal perforation. Operations for the relief of disabilities were numerous. Hernia is represented by 1341 cases. Less common operations are mastoidectomy (89 cases); operations on the nose and eye: on the kidneys, bladder, and prostate: and on the liver, gall-bladder, and gall-ducts. Many cases of bone plating and wiring are recorded. Spinal analgesia has been employed on several occasions, and local anæsthesia is becoming more frequently used for rib resections, varicose veins, etc.

among pensioners and officers on the retired list. From these sources a wide surgical practice is obtained in the treatment of diseases and injuries arising in males after the age of thirteen years. The addition to the Navy of many thousands of auxiliaries of a lower physical standard than the active service ratings has extended the variety of diseases coming under surgical treatment.

It has been the aim of the Administration to give a period of hospital experience to as many medical officers of the fleet as circumstances permit. By this means a large and increasing proportion become well practised in modern methods, and not a few develop surgical skill of a high order. Consequently, in every fleet are to be found officers thoroughly capable of meeting all surgical requirements.

The growth of surgical efficiency in the Navy has been very marked during the past twelve or fifteen years. Up to that time major surgical operations were rarely undertaken. There was a great loss to the Service of men invalided for such disabilities as hernia, varicose veins, etc. Coincident with the more general employment of surgical means elsewhere, the spirit of surgical enterprise arose in the naval hospitals. It did not originate, as might be supposed, from the influx of new blood, or from suggestions by the Administration. It arose from the enterprise of a few pioneers, men of several years' seniority, who, developing a latent ability, with courage and determination fought down prejudice, and laid the foundation for that confidence in the surgical work of our hospitals that is now shown by all ranks of the Service. This growth of efficiency was fostered by the Administration. The hospitals were provided with every surgical necessity. Old operating rooms were re-constructed and new rooms added. *X*-ray departments were instituted. The new hospital at Chatham, built during this period, was furnished with the latest surgical apparatus. Officers were selected and appointed to all the large hospitals as anaesthetists and radiographers. As many medical officers as arrangements permitted received post-graduate courses at recognized schools. These courses included special instruction in operative surgery. Selected sick-berth ratings were trained as operating-room attendants. No difficulty was found in obtaining a succession of senior medical officers capable of taking up the surgical work. There seems to be no doubt that a close association with the strenuous activity that exists in the fighting branch of the Navy develops the qualities of handiness and adaptability. In such practical subjects as surgery, radiography, and bacteriology, the seasoned naval medical officer quickly becomes efficient.

While the practice of surgery was being encouraged in the hospitals by the provision of all requirements, the surgical equipment of the ships was greatly improved. Special stations for the treatment of wounded during action were considered in the design of the vessels, and not left to be

extemporized as had been the custom. These stations were fitted with a supply of hot and cold water, special ventilation, lighting, and equipment generally. Formerly the surgeon had to provide himself, at his own expense, with a regulation set of surgical instruments, a stomach pump, splints, and a few other necessary articles. For some years past all the larger ships have been supplied by the Admiralty with a liberal outfit of instruments, including microscopes, and sterilizing, *x*-ray, and bacteriological apparatus; recently a medical library of reference has been added. These stores are supplied from the naval hospitals, where they are kept ready packed to be issued at a moment's notice.

In addition to being hospitals proper, and centres for distribution of stores, these establishments are training-schools for the sick-berth ratings. In peace time, courses of lectures are given by the staff to medical officers attached to or in the vicinity of the port. For over thirty years the Royal Naval Hospital at Haslar has been a training centre for newly entered surgeons. Within recent years the newly entered have been required to pass an examination at the end of a period of probation before receiving their commissions. During the war all regular courses of instruction at Haslar and Greenwich have been suspended.

At the outbreak of hostilities, fighting-ships in commission, and those newly commissioned, received their war complement of medical officers, sick-berth ratings, and medical stores. The hospitals were brought up to their full war accommodation and staff, and the pre-arranged scheme for overflow to the subsidiary naval infirmaries and temporary hospitals was put into force. This scheme has been considerably expanded, especially in Scotland, to meet the growing necessities of the fleet. Hospital ships have been equipped and staffed. Private yachts, fitted out by their owners, have been taken over by the Admiralty as hospital ships for the transport of the sick and wounded over short distances. A great deal of surgical work has been undertaken in hospital ships, both while acting as mobile base hospitals to the fleets, and while carrying naval and military wounded. A share of this operative work has been borne by temporary surgeons. The employment of hospital ships as mobile base hospitals enables the fleet to use suitable bases without regard to considerations as to the disposal of the sick and wounded; and as these bases or rendezvous may be a considerable distance from the naval establishments ashore, the transport of the acutely sick and wounded is reduced to a minimum. During the military operations in the Gallipoli Peninsula, naval hospital ships in the Mediterranean were employed chiefly in receiving the wounded direct from the dressing stations and transporting them to base hospitals in Egypt, Malta, and elsewhere. Although the number of casualties coming under treatment after naval actions afloat have been comparatively few, the naval home hospitals

have been very full at times, since accommodation has been given to our own and Belgian military, as well as to the sick and wounded from the battalions of the Naval Division fighting ashore. In addition to the arrangements made for overflow to subsidiary hospitals in the vicinity of the ports, provision was made for the reception of cases in some of the London hospitals.

Afloat, the organization for the immediate treatment of the wounded varies with the class of fighting-ship. In all ships the sick-berth is situated in too exposed a position to be used during action. Two main stations are selected, one forward and the other aft, in the best protected and most accessible situations. Here the wounded are brought by collecting stretcher-parties during pauses in the fighting. After treatment they are passed on by distributing stretcher-parties to disposal stations. Many of the cases receive first-aid treatment at the hands of their comrades before they arrive at the receiving stations, for in all turrets and isolated positions dressings, tourniquets, etc., are provided.

The experiences gained in the present war have proved the value of the instruction in first aid given to the ship's company; this is especially noted in unarmoured ships, where it is practically impossible for the wounded to be collected or for the surgeon to reach the wounded during action. In the work of attending the injured the surgeons and staff are assisted by officers and men of the non-combatant branches. All details of this organization are rehearsed frequently in a realistic manner. Of the many forms of apparatus for removing wounded from difficult places, the Neil-Robertson stretcher has proved most suitable.

Before going into action, the men are required to change into clean clothing in order to lessen the liability to septic infection. Sepsis from the presence of virulent micro-organisms rarely occurs afloat. This freedom has permitted the complete closure of severe shell wounds to be made after excision of damaged tissues, with results that are most encouraging. The large proportion of burns on uncovered parts of the body have called for special measures for the protection of the face and hands. The treatment of burns by recent and improved methods is receiving careful attention.

Scientific investigations have been made in the laboratories of the hospitals as to the relative bactericidal power and tissue penetration of various antiseptics: and the practical value of the Dakin treatment of wounds has been the subject of a special commission of experts. In this experimental work, as well as in surgery, medicine, bacteriology, and anaesthetics, the regular medical officers have received the greatest assistance from consultants and temporary surgeons. The services of the probationary surgeons—i.e., advanced students, not yet qualified, engaged during the war—must not pass unnoticed. These young men, in medical charge of scouts, destroyers,

and other small craft, have accepted the responsibilities and the risks of their dangerous employment with courage and devotion to duty.

When peace is restored and stock is taken of our professional experiences, we shall realize to the full how greatly the Naval Medical Service has benefited by the close association of its members with representatives of all grades of civilian fellow-workers. We may anticipate with confidence that not the least of the advantages arising from this comradeship will prove to be a more general appreciation of the wide variety of practice, the certain recognition of merit, and the many opportunities for professional advancement, that are offered with a surgeon's commission in the Royal Navy.

ARTHUR W. MAY.

JOHN BANESTER.

1533–1610.

The commemorative picture which shows John Banester lecturing on anatomy gives several interesting details about him. There is in the first place the record of his age, 48 in the year 1581. He was born, therefore, in 1533. Secondly his armorial bearings, with the appropriate cadency sign, showing that he used the coat armour* of the Banisters of Cobham, and that he was the second son. It follows that he was the second son of John Banister of Cobham, who was one of the Barons of the Exchequer. His books are dated, however, from Nottingham, where he lived for some years. He had relatives there, for the Chamberlain's accounts for the year 1573 record: "Item, given the same day [July 17, 1573] a pottell of wyne and halfe a lb of seugar unto Maister Banyster the Preacher." He may also have had a connection with the Barbers' Company, for a John Banister appears seventy-ninth on the list of members of this Company in 1537.

The first fact now known about him was that he acted as Surgeon to the Forces sent to relieve Havre under the Earl of Warwick in 1563. Here he probably formed a life-long friendship with William Clowes, who speaks of him as "Master John Banester, my dear and loving friend"—a friendship which led Clowes to introduce each of Banester's works with commendatory verses, and to write a long epitaph in verse, which was destroyed when St. Olave's, Silver Street, was burnt in the Great Fire of London.

In 1572 Banister was admitted a member of the Barber Surgeons' Company, and there is a note still extant in the records saying that "Mr. Banester of Nottingham was sworn and admitted a brother of this mystery. Whereupon he hath granted to the House yearly twenty shillings so long as he liveth and to be liberal and commodious to this house in that he may, and will yearly send a buck or two and hath paid ten shillings and shall have his letter of licence." The note is as remarkable as it is unusual. The friendship of Clowes, or Banister's own family interest, may have gained him admission to the Company—for it is evident that he was never apprenticed—but it was not everyone living in the reign of Elizabeth or in the neighbourhood of Sherwood Forest who could promise to send a buck or two yearly so long as they lived. It is clear, therefore, that he had considerable influence.

In 1573 the University of Oxford granted him a licence to practise physic. The record runs: "Banister John after seven years in medicine supplicates for a licence to practise medicine 30th June 1573." He thus acted both as a physician and as a surgeon, a most unusual combination at a time when the surgeons were still held in thraldom by the physicians.

* Argent, a cross fleury sable. Crest: a peacock sitting, taking in its beak a serpent twined proper round its neck, all proper.

JOHN BANESTER DELIVERING THE VISCERAL LECTURE AT THE BARBER SURGEONS' HALL, LONDON, IN 1581.

In 1581 he lectured at the Barber Surgeons' Hall in Monkwell Street, his predecessor being Thomas Hall, the son of John Hall of Maidstone, who was appointed in 1577. In 1585 he served on board ship during the Earl of Leicester's expedition to the Low Countries, and on February 15, 1593–4 he was licensed to practise medicine by the Royal College of Physicians of London, in obedience to a letter signed by Elizabeth, "given under our signet at our manor of Otelands, the xxviiith day of July in the xxxvth year of our reigne." The reason assigned by the Queen for desiring this favour was that "he desireth to end his old yeares in quietness, as I trust he shall do unless he happened to be molested by any of your College." The College dared not disobey the request, repugnant as it must have been, since Banester was a surgeon. They granted it, but added the condition that "in omni graviori morbo et pleno periculi unum aliquem ex Societate Collegii ut adjutorem sibi in illa curatione accersat et adjungat (in every serious and dangerous case he must call in some one else belonging to the College). In 1578 he was living at Nottingham; in 1585 he had moved to London, and lived in Silver Street, where he died in 1610; he was buried in St. Olave's Church in the same street.

Banester wrote: (i). *A needefull, new and necessarie treatise of Chirurgerie, briefly comprehending the general and particular curation of Ulcers taken foorth of sundrie worthy wryters, but especially of Antonius Calmetus Vergesatus and Joannes Tagaltius. Imprinted at London by Thomas Marshe. Anno* 1575. The work is a duodecimo, dedicated to "the Right Worshipfull maister Thomas Stanhope Esquire and high sherife of Nottinghamshire this present yeare of oure Lorde 1575." Following the epistle dedicatory are twenty-five stanzas of verse by the author in praise of "Physicke and Chyrurgerie," which is again followed by an epistle dedicatory to "the Worshipfull Maister, Wardens and generall assistauntes of the fraternity of Chyrurgians in London," and dated from "my house in Nottingham the vi of June 1575." The consideration of the degraded state of surgery again moves him to verse, and he apostrophizes "evil and counterfeit dealers in the art of Physic and Chirurgerie." This apostrophe is followed by commendatory verses by Richard Smith and William Clowes, George Baker, and others, who as surgeons write in praise of the author. The book itself is of no interest. It is a mere dull compilation, without the illustrative cases which enliven the pages of Clowes and Gale.

(ii). In 1578 Banester issued in folio *The Historie of Man sucked from the sappe of the most approved Anathomistes, in this present age compiled in most compendious fourme and now published in English for the utilitie of all godly chirurgians within this Realme.* It was printed by John Day. The plates are copied from Vesalius. They have been re-drawn, reduced in size, and the backgrounds altered. As an anatomist Banester prefers Columbus, a point which he has had emphasized in his picture, where he chose to be represented in the act of lecturing from a passage in this author. The introductory verses are again by Clowes. The book itself is without interest.

(iii). *A Compendious Chyrurgie gathered and translated especially out of Wecker at the request of certaine . . . published for the benefit of all his countreymen by Iohn Banister Master in Chyrurgerie.* The book is a duodecimo "Imprinted by Jon Windet for T. Man and W. Brome." It is

dated "the xxvii of October from mine house in Silver Street." In moving to London it may be noted that the author had changed the spelling of his name from Banester to Banister. The book, like the other two, is uninteresting, except for a short series of four-line stanzas addressed respectively to the Reader, the Printer, and the Translator. The verse "to The Printer" may be given as an example:—

Haste to the presse, feare not the sale.
  good wine doth neede no signe ;
The Surgeons craue this worke to haue ;
  the gaine it will be thine.

A collected edition of Banister's works was published in 1633 in six books as a small quarto. The dedications and the text are left ; but the poetry, having no doubt served its generation, has fallen on sleep.

It appears after reading Banister's books that he was never a surgeon in the sense that Clowes, Gale, and Barrough were surgeons. He occupied the position of a professor of surgery, and was the exponent of other men's views. He was a teacher rather than a practitioner of his art. As such, he would have no claim to notice in a journal of surgery ; but he holds a definite place in the history of English surgery, because it is clear from his prefaces that he was heart and soul with those who, like Clowes and Gale in London, and Hall and Read in the provinces, made a determined attempt, during the reign of Elizabeth, to raise surgery from a trade to a profession. The attempt was made in several directions, partly by improving the examination for surgeons, partly by emancipating surgery from medicine, partly by demonstrating the ignorance of the quacks who then flourished so luxuriantly. But the time had not yet come, and their efforts ended in failure. The surgeons still remained subordinate to the physicians ; the examination for admission to the Barber Surgeons' Company was nullified owing to the recommendations of unsuitable persons by powerful patrons, and the quacks continued to multiply in numbers and in influence. Banister either by his personality or by his influence held a higher social position than the other reformers. He alone was admitted to the College of Physicians, and he alone was granted a licence to practise by the University of Oxford. Yet his heart throughout was with Clowes and "The worshipfull the Maister Wardens and generall assistauntes of the fraternitie of Chyrurgians in London to whom John Banister (a member of the same) wisheth to them all, the true direction in the perfect way of knowledge to this misterious science according to their profession." He seems in fact to have lent to the movement the same sort of prestige that Pusey lent to the Tractarian movement. Like Hall, Clowes, and Gale, he hated quacks heartily, and addressed them in no measured language in the preface to his *Anatomy*: "As for you, O ye chaff of the earth, ye stinge of the Godly, ye impes of Hell and children of wrath, you (I say) that under the pretence of the sacred arte of medicine, devoure the sheepe of God's pasture, flea the labourers in his harvest and denye your Lord the fruits of the vineyard, since no warninges may admonish you, no exhortation amende you, no lawes bridle you, no punishements turne you, nor any feare of God sinke into youre brestes, I, from the depth of my hart renounce you, hopying

assuredly that from none of the flowers of this Garden any of you shall take opportunity to sucke that, which may maintaine the infection of your pestilent wretchedness hereafter." Indeed he gave his daughter Cicely in marriage to John Read, one of the foremost of the reformers, whose early death must have been a severe blow to the cause.

Clowes's epitaph, even allowing for exaggeration, seems to show Banister as a generous and humane practitioner :—

Thy Skill and Practice, that itself commends
  Some of the best have truly found the same
Not partially employed to wealthy Friends,
  But even the poorest Wretch, the Sick and Lame
Felt of the best ; some Difference there might be,
  The Rich paid somewhat, poore Men had it free.
The Weekly Charity given to the Poore
  In Bread beside, in Money from thy Purse,
Even in the hardest yeares dealt at the Doore.
Poore maymed Souldiers, sore sick-hearted Men
  That under Miseries hard Crouch did bow,
Were freely cured, methinkes they cry, Lord, when,
  Where shall we find our good Physician now ?

The original of the picture which is here reproduced is in a volume of 'Master John Banister's Anatomical Tables," in folio, which is in the Hunterian Library at Glasgow. The picture is double page, mounted on guards, and backed with modern white paper. It represents John Banister delivering the "visceral lecture" in the Barber Surgeons' Hall at Monkwell Street. The carefully painted figure in the Master's hat and the furred gown is probably the Master of the Company for the year 1581. If so, he is Robert Mudesley, to whom Thomas Vicary bequeathed "my best single gowne faced with black satten." He is also mentioned in the 1569 grant of arms as one of those governors of the Barber Surgeons' Company who petitioned for some permanent mark in their armorial bearings* to commemorate the union of the Barbers and Surgeons. The grant by letters patent took the form of "an augmentation in chief to their old and auncient arms with heaulme and crest to the same." It was perhaps for this reason that the painter has introduced the new coat of arms into the picture, containing a lion of England and two crowned Tudor roses.

The two senior stewards of anatomy are distinguished by their badges. It was enacted in 1555 that there should be chosen every year two "for the Anathomye and other two also to be chosen for to be stewards ; so that two always shall stande for ij yeres because they that doo not worke of the

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* The arms of the Barber Surgeons are those granted to the United Company by Sir Gilbert Dethick, Garter King at Arms, in 1569. They are : "Quarterly the first sables a cheveron betweene three Flewmes argent ; the seconde quarter per pale argent and vert on a spatter of the first, a double Rose gules and argent crowned golde ; the third quarter as the seconde and the fourth as the first. Over all on a Crosse gules a lyon passant gardant golde ; And to their Creaste upon the heaulme on a Torce argent and sables an Opinacus golde ; Mantelled gules doubled argent : Supported with two Linxe in their proper coulor about their neckes a crowne with a chayne argent pendent therat." The motto "De praescientia Dei," which is still used by the Company of Barbers, now first appeared in the armorial bearings of the Barber Surgeons.

Anatomy the one yere being Stewards for the provysyon of victualls they shall worke the other yere following. And they that shalbe chosen shalbe alwayes for the first yere Stewards, because that they shall see the makynge of them the yere before that they may be the more practysed in the doynge the next yere the sayed Anathomye that after it maye appeare by the workmanship that they be the dooers. Yf the Master and governors do goo about to breake the same acte they shall lose for a fyne to the hall xls."

The class consists of the members of the Barber Surgeons' Company, who were obliged to attend the lectures under penalty of a fine.

The picture is interesting from many points of view, and first historically. It represents almost with the accuracy of a photograph the method of conducting anatomical teaching in London at the end of the sixteenth century, and, so far as is known, it is the only illustration of the lectures given at the Barber Surgeons' Hall. It furnishes additional facts about John Banister. It is clear that he was the Company's visceral lecturer in 1581, which was not previously known. The minute accuracy of the picture is shown by the vade mecum which is used as the text of the lecture, and it will be noticed that the skeleton is supported and crowned with the colours of the Barbers' Company, and a wreath of the same surmounts the helmet in Banister's arms. The book on the reading desk is "Realdus Columbus," and from its size it might be the folio edition printed at Venice in 1559. Reference shows, however, that the passage in this edition is on folios 227 and 228. The picture gives the pages 419 and 420. An octavo edition was published at Paris in 1572, and in Chapter 5 of Book xi the latter part of the passage quoted is found, just as the painter saw it, on pages 419 and 420. The minute detail is also shown in the drawing of the scissors, the different shapes of the dissecting knives, the double-headed retractor held by the steward of the anatomies, and by the Company's badges worn by the lecturer and stewards. Of the drawing from the artistic point of view it is less easy to speak. The two main figures of John Banister and the Master of the Company seem to be careful studies from life; the stewards and the audience are less carefully drawn. The body seems to have been drawn from the actual subject, who has a shrunken right leg—perhaps the result of old infantile paralysis—for the right foot is in a valgus position. The lecture is given on the passage: "Intestina igitur a ventriculo exoriuntur, eademq'; penè substantia videntur: licet aliquantulum tenuiore. Situs eorum est ab inferiori ventriculi orificio ad anum usque, abdominisq'; majorem partem occupant. Veteres Anatomici intestina in sex partes distinxere, distinctisque singulas nominibus appellauere. Ego verò si post tot seculorum recepta vocabula noui aliquid in medium proferre fas esset, intestina duo esse dicerem, quorum alterum tenue est, crassum alterum. Sed ut aliorum vestigia sequamur; (neque enim temere a veterum placitis discedendum est), sex esse dicemus intestina, duodenum, inquam, jejunum, ileon, coecum, colon, rectúmque."

Throughout the Middle Ages the surgeons of London were taught systematically and practically. The Barber Surgeons' Company, from its formation in 1540, organized a regular staff for the purpose, consisting of a Lecturer, who was sometimes a member of the Company but was more often a young physician fresh from Oxford or Cambridge, of four assistants, sometimes called

'Masters' and sometimes 'Stewards' of the Anatomies, and an audience consisting of the members of the Company. The subjects were obtained from the place of execution, and were four malefactors yearly. The lectures were three in number, the 'osteological,' the 'visceral,' and the 'muscular,' and great care was taken that they should be conducted decently and in order. They were public, or at least so public that any person could attend upon the introduction of a member of the Company, and they ended with a dinner, which was one of the most important annual functions of the corporation. The following extracts will give an idea of the conduct of the business:—

"The body having been brought to the Hall," it is ordered in 1567, "there shal be pyllars and rods of iron made to beare and drawe Courtaynes upon and aboute the frame where within the Anathomy doth lye, and is wrought upon, for bycause that no person or persons shall beholde the dissections of the body, but that all may be made cleane and covered with fayer clothes untyll the doctor shall come and take his place to read and declare upon the parts desected. And also yet fordermore that there shal be a case of weynscot made with paynter's worke upon it, as seemly as may be done for the skelleton to stand in."

Care was taken not only in choosing the lecturer, but his material comfort was provided for. It was enacted in 1555 that the stewards "which be appointed for the Anathomye for the year next following must sarve the Doctor and be about the body. They should see and provide that there be every yere a matte about the harthe in the hall that Mr. Doctor [be] made not to take colde upon his feete, nor other gentlemen that doo come and marke the Anatomye to learne knowledge. And further, that there be ij fyne white rodds appointed for the Doctor to touche the bodye when it shall please him, and a waxe candell to loke into the bodye, and that there shall be alwayes for the Doctor two aprons to be from the shoulder downwarde: and two payre of Sleaves for his hole Arme with tapes for chaunge for the sayed Doctor, and not occupye one Aprone and one payr of Sleaves every day, which ys unseemly. And the Masters of the Anathomye that be about the bodye to have lyke aprones and sleaves every daye both white and cleane, yf that the Masters of the Anathomye that be about the Doctor do not see these thinges ordered and that their knyfes, probes and other instruments be fayer and cleane accordingly with Aprones and Sleves, if they doo lacke any of the said things afore rehersed he shall forfayte for a fyne to the hall xls."

It is to be remembered, too, that if fines were not paid, the Company had the power of summary committal to the Compter or even to Newgate.

The attendance at the lectures was compulsory. The ordinance of 1572 enacts that "every man of the company usinge the mystery or facultе of surgery, be he freman, fforeyne, or alian straunger shall come unto the Anathomye, being by the Beadle warned thereunto. And for not keepinge their houre both in the forenoone and also in the afternoone, and being a freman shall forfayt and paye at euery tyme iiijd. The fforeyn in like manner and the Straunger euerye tyme vjd. The said fynes and forfaytes to be employed unto the Anathomysts for the tyme beynge, towards theire charges within the tyme of the sayd Anathomye. And also for not comyng in all the tyme of the Anathomye (having lawful occasion of absence) the

Freeman shall pay vjd., the fforreygne vijd., and the Straunger xijd. And to be employed in manner and fourme aforesaid. And also iijs and iiijd. to the Masters and Gouernoures of the said Mystery for their summons brakinge notwithstanding. Provided also that they come well and decently appareyled for their own honestye, and also for the worshippe of the companye."

The following directions, which were evidently given by an old clerk of the Company to his successor new to the office, show how the business of a lecture was conducted. They are headed: "Form of the business at the time of a Public Demonstration of Anatomy."

"So soon as the body is brought in deliver out your ticketts, which must first be filled up as followeth—4 sorts: The first fforme to the Surgeons who have served the office of Master you must say, Be pleased to attend, etc., with which summons you send another for the demonstrations; to those below the Chaire you say, Our Masters desire your Company in your gown and Flatt Cap, &c., with the like notice for the Demonstrations as you send the Antient Master Surgeons. To the Barbers, if Ancient Masters, you say, Be pleased to attend in your Gound only; and if belowe the Chaire then, Our Masters desire, etc., as to the others above without the Tickett for the Demonstrations.

"The body being by the Masters of Anatomy prepared for the lecture (the Beadles having first given the Doctor notice who is to read, and taken orders from the Master or Upper Warden of the Surgeons' side concerning the same), you meet the whole Court of Assistance in the Hall Parlour, where every gentleman clothes himself, and then you proceed in form to the Theatre (vizt), the Beadles going first, next the Clerk, then the Doctor, after him the severall gentlemen of the Court. And having come therein, the Doctor and the rest of the Company being seated, the Clerk walks up to the Doctor and presents him with a wand and retires without the body of the Court until the lecture is over, when he then goes to the Doctor and takes the wand from him with directions when to give notice for the reading in the afternoon, which is usually at five precisely, and at One of the clock at noon, which he pronounces with a distinct and laudable voice by saying: 'This Lecture, Gentlemen, will be continued at Five of the clock precisely': having so said, he walks out before the Doctor, the rest of the Company following down [to] the Hall Parlour, where they all dine, the Doctor pulling off his own robes and putting on the Clerk's gownd first—which has been usuall for him to dine in—and after being plentifully regaled, they proceed as before untill the end of the third day, which being over (the Clerk having first given notice in the fforenoon that the lecture will be continued at Five of the clock precisely, at which time the same will be ended), he attends the Doctour in the Cloathing Room, where he presents him, folded up in a piece of paper, the sum of 10 li.;0;0, and where afterwards he waites on the Masters of Anatomy and presents each of them in like manner with the sum of 3 li.;0;0, which concludes the duty of the Clerk on this account.

"N.B.—The Demonstrator, by order of the Court of Assistants, is allowed to read to his pupills after the Publick Lecture is over for three days and untill Six of the clock on each day, and no longer, after which the remains of the body is decently interred at the expense of the Masters of Anatomy, which usually amounts unto the sum of 3;7;5."

A STUDY OF THE INTER-RELATION BETWEEN THE RADIOGRAPHY AND SURGERY OF GUNSHOT WOUNDS OF THE HEAD.

By Captain H. E. GAMLEN, R.A.M.C. and Captain S. SMITH, R.A.M.C.

At this General Hospital we have a record of at least 1500 radiographs of gunshot wounds of the head taken during the past eighteen months, a large proportion of them involving the skull and underlying brain. Thus we can lay claim to a considerable experience in the taking and interpretation of such radiographs.

Apart from the clinical picture, the factors which influence us when the question of operative interference comes to be discussed are: (1) The local condition of the wound; (2) The x-ray appearance. In deciding upon the value of the second factor, it is important that the surgeon and the radiographer should work in harmony, each surgeon examining the radiographs of his own cases and discussing them with the radiographer: for no surgeon without considerable experience in this work can interpret his own plates without help from the expert. A dried articulated skull is of great assistance in forming a good mental picture of the anatomy of the lesion: and just prior to the operation the radiographs should again be inspected, so as to revive the picture clearly in the memory of the operator.

We have divided our paper broadly into three sections:—

1. *The Method employed in taking the Radiograph*, discussing fully our technique where it has seemed to differ from that in common use.
2. *The Interpretation of the Radiograph.*
3. *A Classification of the Type of Injuries Revealed by the Radiographs*, and a discussion of the surgical practice adopted for each type.

I. METHOD OF TAKING THE RADIOGRAPHS.

We would at the outset insist that stereoscopic views should be taken in every case, being firmly convinced of the paramount importance of this method, which enables one as it were to look right into the patient's head, and to view in relief the injury to the various strata as it really exists.*

In radiographing these cases of head injury as we get them, comparatively soon after the infliction of the wound, special difficulties present themselves. The patients are often in a peculiar mental state, maybe restless or delirious. Consequently it may be necessary in certain of the cases to give an anæsthetic to ensure a reliable result. Short of this, rapid work with

* The illustrations in this article are printed each from a single plate of a stereoscopic pair, and consequently fail to show the depth of strata which is essential for the surgeon.

intensifying screens, necessitating an exposure of only a few seconds, may overcome the difficulty. The majority of slightly restless patients can be kept still, however, for the ordinary exposure of twenty seconds, with a compression cylinder, by making use of a paper air-cushion wedged between the head and the compressor.

The size of the plate, position taken, condition of the tube, number of milliampère-seconds given, and distance of the plate from the anode, are tabulated. Careful notes are also made on the final treatment of the plate, whether it is normally, under-, or over-exposed, and whether correctly, under-, or over-developed. Finally, the radiographer's diagnosis is added. These reports are standards for future work. Reduced stereoscopic slides are sometimes made, which often give a clearer and more instructive view with the hand stereoscope than the original negatives, because in reproduction any fault in density may be overcome.

Technique Employed.—As a preliminary, a small lead wire ring is placed over the wound surface, a clean new ring being used for each case.

At the outset it is necessary to decide in what position it is best for the head to be fixed for any given wound. In addition, the relation of a retained missile to the wound of entry, and the probable direction of any brain track, should be known. If time allows, therefore, a preliminary screening should be done, in order to give some idea of the position of the missile, which can generally be quite easily seen. Only in exceptional cases can one by screening follow the line of fractures, although if there be a large bone defect it can often be seen, as can also the track made by a large foreign body.

The wound surface should always be that nearest to the plate, with the area immediately surrounding the wound actually in contact with it, since in viewing the stereoscopic radiographs afterwards, the best results are obtained by viewing through the healthy on to the injured side.

If the wound and the position of the missile as viewed through the screen lead one to believe there is a track running in any given direction, experience has shown that the most satisfactory results are obtained by radiographing this track at an angle.

It is evident that the knowledge gained by screening, of the best possible route, and of the line of least resistance to the rays in various parts of the skull, greatly facilitates the work. Thus, in taking lateral views, we always endeavour to centre our rays through the squamous temporal, as offering less resistance than the thicker regions of the skull.

The condition of the tube, and the exposure, have often to be altered to suit the particular view which is to be taken. A lateral view, for instance, requires different conditions from an anteroposterior view in order to obtain the best results.

Of necessity the supine position is that selected for the majority of our cases, as few of them are sufficiently recovered on arrival to allow of any other position. If he has a short neck, the patient may find some of the postures uncomfortable, but this difficulty can usually be overcome by allowing him to rest on his side with the plate-holder raised to a higher level than that usually employed, using wooden wedges where necessary.

When correctly adjusted, the head is fixed by means of paper air-cushions,

partly inflated, which are placed between the head and the compressor. These take a grip of the greater portion of the head facing the tube, and an extra push downwards of the compressor makes any movement impossible. The radiographs are usually taken with the head in the lateral position, centring just above the external auditory meatus. If, however, the injury is near the vertex (this embraces the very important class of sinus injuries described by Sargent and Holmes), the head is tilted so as to allow the vertex to be nearer the plate than the base; and vice versa, if there be an injury in the neighbourhood of Reid's base line, the base is approximated to the plate.

Slight manipulation of the skull in its relation to the plate, with a view to bringing the injured area as near the central rays as possible, brings out many details not otherwise obtained. In certain special cases, the indications for which will be described later, radiographs of the cranium are taken in an anteroposterior direction, the face being placed on the plate and the rays passing directly through the skull from behind forwards; central rays are then made to hit the back of the skull one and a half inches either above or below the inion.

The distance of the anode of the tube from the plate varies from 58 to 64 cm., and the diaphragm is cut down so that both radiographs (stereoscopic) are just contained in the circle of illumination. The tube shift is 6 cm. The length of exposure varies with the age of the individual, old people requiring a longer one than young. The breadth of the head has to be taken into account, but as a general rule 120 to 140 milliampère-seconds are sufficient for lateral views, with an addition of about 30 per cent for anteroposterior positions of the skull. Until recently we have always had a vacuum tube in circuit; but lately we have replaced this by a mechanical rectifier, which successfully prevents any of the inverse current from entering into the *x*-ray tube. The best work is done with the tube in a condition of 6 to 7 Bauer, the development being carried on from 15 to 18 minutes. Plates thus taken will show the contour of the skull on both sides when viewed stereoscopically. The majority of the lines of shadows are cast by the side of the head which is nearer the plate, and can be increased or decreased at will by varying the distance of the tube from the skull. These shadows can still further be modified during the development of the radiographs.

Positions of the Head.—As a result of our experience and of many trials, we now always fix the patient's head in one of the seven positions about to be described. The position varies according to the situation of the wound. From our records we find that the majority of wounds of the cranium occur over the temporoparietal area (50 per cent), next in order come those over the frontal area (25 per cent), and finally those over the occipital area.

A. Lateral Views.—

Position 1.—Particularly adapted for showing injuries to the lateral aspect of the frontal bone, the temporal bone, and also the parietal bone except at the summit. Lateral view centred at the temporomaxillary joint at the level of Reid's base line.

On looking from the healthy to the wounded side, a good view of the whole of the lateral aspect of the frontal and parietal bones is obtained, except towards the summit, and the squamous temporal is also well seen. We can

trace the edges forming the boundaries of the lateral sinus from the torcular forward as far as about the middle of the petrous bone, where the sinus sinks below the dense shadow cast by this bone—though towards the anterior part the edges become indistinct owing to their overlapping. The whole of the grooving for the superior longitudinal sinus can be made out, most distinctly in the anterior frontal and posterior occipital regions. Lateral views of the orbital plates of the frontal bones are seen, and the pituitary fossa and clinoid processes are very distinct. If, as sometimes happens, the sphenoidal cells are large and occupy a great part of the body of the sphenoid, they show up well. In this position the two temporomaxillary joints overlap, and consequently an indistinct view of these is seen. Overlapping views of the rami of the inferior maxilla are also obtained.

Position 2.—Adapted for showing the posterior parietal, temporal, and occipital regions. Lateral view centred at the base of the mastoid.

A better view of the orbital plates of the frontal bone is obtained than in *Position* 1, since the overlapping is not so marked. The pituitary fossa and clinoid processes are still well seen. A good view is obtained of the petrous bone throughout the greater part of its length. The anterior part of the lateral sinus is also seen better than in *Position* 1. In looking through the uninjured to the injured side, we see less of the contour of the temporal, parietal, and occipital bones than in *Position* 1. A very good overlapping view is also obtained of the inferior maxilla, provided the mouth is open.

By centring at a slightly higher level, say the level of the upper attachment of the pinna, we obtain a view looking into the cavity of the cranium from above. By centring thus, a better view is obtained of the orbital plates and of that part of the squamous temporal above and in front of the apex of the petrous bone. The bony landmarks around the foramen magnum are well brought out by this view.

Position 3.—Specially adapted to show injury to, or in the neighbourhood of, the superior longitudinal sinus. If an injury is seen at or near the vertex, the head is tilted so as to allow the vertex to be nearer the plate than the base. This is done by placing an air-bag under the shoulder and neck, so that the mastoid is 1 to 1½ inches above the plate, and the central line of the vertex considerably nearer it than occurs when the two methods previously described are adopted. The base line is centred as appears most convenient, depending on the position of the wound.

When looked at from the uninjured to the injured side, we obtain an excellent view of the whole of the inner aspects of the frontal and parietal bones, together with the greater part of the occipital bone. The bones which go to form the bed of the superior longitudinal sinus are also well seen, the position now described being especially adapted for fractures in this neighbourhood. Previously, when lateral views were the only ones taken, thus allowing the opposite parts of the skull to overlap, one often experienced great difficulty in reading the radiographs, especially when the bony injury crossed or was in the neighbourhood of the several sinuses; slight fractures with depression of the inner table have been mistaken for lacunæ, the markings of blood-vessels, or overlapping of ridges which go to form the sinus. It was soon found that these defects could be overcome by tilting the head in various

ways so as to prevent the overlapping of the opposite shadows, and now we experience no difficulty in revealing fractures over the superior longitudinal and lateral sinuses.

A good view of the posterior surface of the petrous bone is obtained on the injured side, and also of the under surface of the base of the skull.

On reversing the plates, we have a still better view of the bones forming the upper half of the cranium, but not so extensive a view of the base as seen from above. A good anterior view of one petrous bone, and both aspects of the other, are shown. The torcular and the occipital sinus are well seen. In the event of the radiograph being taken with the mouth open, we obtain a good view of the temporomaxillary joints, and both sides of the inferior maxilla are very clear except in the central line, where the shadows overlap at the chin.

Position 4.—Specially adapted to show injuries at the base of the skull, the posterior mastoid, the occipital bone, and the lateral sinus. Great care has to be taken with this position in order to obtain the results desired. The head is first placed flat on the plate-holder, and an air-cushion introduced under the vertex and so arranged that the front of the head is at a higher level than the back. The plate is pushed so that its lower end rests under the third or fourth cervical vertebra, with the mastoid process resting firmly on the plate. By centring exactly two inches above the external auditory meatus, the central rays will pass in just posterior to the petrous bone; 10 per cent increase of exposure over the normal is allowed for this view.

On looking through the healthy on to the injured side of the skull, we obtain a good view of the orbital plates and the lateral aspect of the frontal bone, and of most of the parietal bone. Provided the angle is correct, a perfect view of the temporal and occipital bones is given.

If we centre a little higher, the lateral sinus throughout most of its extent, and the region of the foramen magnum, with the first and second cervical vertebræ, are added to the above view.

On reversing the plates, the base of the skull as seen from the underside is very distinct. With the mouth open, a good view of the inferior maxilla and of both temporomaxillary joints is obtained. This is the most suitable view for dental surgery, as there is no overlapping of the structures of the mouth.

B. Anteroposterior Views.—

Anteroposterior views of the head and neck are particularly useful for localizing the position of foreign bodies in relation to the central line.

Difficulties have been experienced in the past in giving the exact position of a missile lying in or near the body of the sphenoid, the anterior portion of the foramen magnum, or the bodies of the first to the third cervical vertebræ. The results obtained by operations undertaken for the removal of missiles lying in any of these localities vary very greatly according to the exact position of the missile and the relative ease with which it can be approached and removed by the surgeon. Consequently great attention to detail is essential. In the first place, if the correct exposure for a lateral view is known, an addition of from 25 to 30 per cent, using a tube low in vacuum, will give the best results. The head also must be securely fixed and centred. If good lateral views have already been taken, there is no necessity to

screen; otherwise one always screens, with the tube below the couch, using a high milliampèrage and a diaphragm cut down to give a minimum opening.

Two particular difficulties that have to be overcome in these antero-posterior views are:—

1. The broad horizontal band of shadow cast by the petrous bone. It is essential that, by tilting the head in a vertical plane, this shadow be prevented from overlapping that cast by the missile, or the value of the resultant picture will be much diminished.

2. The shadow cast by the lower jaw. This difficulty can usually be overcome by opening the patient's mouth to its widest extent, and fixing it in this position by a piece of cork placed between the teeth.

Position 5.—The plate rests on the forehead, and lightly touches the nose, the chin being two inches above the plate.

In this view the shadows cast by the petrous bone pass across the level of the upper part of the orbit, and it is only structures or foreign bodies within the skull above the upper limit of this shadow that are distinctly seen. We obtain a fairly clear view of structures lying immediately beneath the skull, particularly the first to the third cervical vertebræ, the pharynx, maxillary antrum, etc. Foreign bodies in the face below the level of the orbit can also be well seen.

Position 6.—The plate rests on the chin and the tip of the nose, and the central rays strike the back of the cranium at a slightly higher level.

The dark shadow cast by the petrous bone now obliterates the lower part of the antrum, but leaves a full view of the forehead, orbits, and upper part of the antrum. The greater part of the temporal and sphenoidal bones are well seen. With the mouth widely opened, a good view is obtained of the anterior aspect of the occipital bone, the foramen magnum, and the first three cervical vertebræ.

Position 7.—The plate again rests on the chin, but is separated an inch from the tip of the nose. This position is obtained by means of an air-cushion, resting on the forehead, between it and the plate. The central rays pass through the back of the cranium at the inion or just above it. It is necessary to further increase the amount of exposure to obtain the best results.

In this view the shadow cast by the petrous bone has moved still further down the face, and now lies at the level of the teeth when the mouth is closed. Within the cranium there is an unobstructed view of the interior. Below the level of the skull a further view of the region around the foramen magnum is obtained. The frontal and sphenoidal sinuses and the ethmoidal cells are particularly well shown. A good view of the whole of the antrum, nose, and orbits is obtained.

II. INTERPRETATION OF RADIOGRAPHS.

All those who have written on gunshot wounds of the head in the present war seem to be unanimous as to the paramount importance of a good x-ray photograph being taken as a preliminary to any operative interference, unless there be specially urgent reasons for performing an emergency operation.

In many cases which have come down the line after having been already

operated on in front-line units, a radiograph taken at this base hospital has shown flakes of bone and shell fragments still remaining embedded in the brain, in quite accessible positions. Secondary operations have often been necessary; the trephine opening, often a small one, has had to be enlarged, and the fragments, commonly the centre of a foul-smelling abscess, have had to be removed. One need hardly say that the mortality is high where such secondary operations have been necessary. We conclude from our experience of many of these cases, that if a radiograph was taken at all at the front, it must have been only a flat negative. One cannot insist too strongly on the necessity of stereoscopic pictures being taken in every instance, and with the greatest possible amount of detail. In viewing these plates through the stereoscope, it is important to have some method by which the light can be regulated, either generally, or locally in part of the field, for often a fracture invisible with a bright light is brought into view with a dimmer illumination.

In certain cases the lobulations of the brain itself can be distinctly seen. Particular attention is drawn to the fact that when a layer of blood-clot lies over the cortex, such an area of injury is seen less distinctly than is the surrounding brain, which fact has proved of some diagnostic value.

Foreign Bodies.—

Method of Localization.—By the use of a pair of compasses and a scale, one can in a few seconds give the size and depth of a foreign body below the wound surface once good stereoscopic negatives have been obtained, thus doing away with much of the elaborate machinery which has come into such prominence during the present war. On each plate appears the shadow of a pair of cross-wires at right angles to one another and in close proximity to the plate. The tube is moved a known distance between the two exposures in a direction parallel to one of the cross-wires. This causes the shadow of any foreign body to shift along the line. By the use of a pair of compasses one measures the distance of the foreign body from the other wire in each case. The difference between the two measurements gives us the shift of the shadow. There is a simple geometric relation between the shift of the tube, the shift of the shadow, and the distance between the anti-cathode and the plate. The shadow shift having been measured, it requires only a moment's calculation by the use of a slide-rule to determine the depth of the missile.

In reading such radiographs stereoscopically, one has to make allowances when, say, a dense white object, such as a bullet or shell fragment, is viewed against other objects the groundwork of which is not of so dense a composition, such as bone or soft tissues. The denser object will always appear nearer the observer than it really is. But as this occurs again when the plates are transposed, the fallacy is repeated, and the error can easily be corrected by experience, as there are so many other detailed parts in the field which can be brought into alinement.

Alterations in Position.—Some radiograms show that the missile has travelled in a zigzag direction before becoming stationary; in one case we were able to show clearly three distinct tracks due to the missile having twice been deflected at an angle. But apart from the clear proof that missiles are occasionally deflected in their flight within the skull, there is another possibility that has been discussed by surgeons—namely, as to whether a retained

foreign body may suffer secondary displacement as the result of falling downwards under gravity. From the evidence gained by frequently re-radiographing heads with retained missiles, we have come to the conclusion that there is rarely a late movement of the missile through the brain. In one case, however, at the first examination a damaged area was found extending beyond the foreign body, and a later radiogram showed that the missile had now travelled a short distance beyond its original situation, having indeed dropped forward into the area of ploughed-up and softened brain that already lay in front of it. But this type of movement is quite a different matter from that of a missile travelling later by its own weight through healthy brain. We have had the opportunity of viewing several radiographs which were supposed to demonstrate free movement beyond the track of a missile, but we have failed to convince ourselves of this movement, as in all cases examined, the second radiograph was taken in a different position from the first. Unless there is exact reduplication of the position of the head in the radiographs, the altered position of the missile is difficult to prove.

Distinguishing Characteristics.—It is sometimes difficult to distinguish between pieces of shell and of lead, and also between these missiles and bone fragments turned on edge. Rifle bullets end on to the plate may be mistaken for shrapnel balls. The distinction between lead and shell-casing is important when the question of the use of the magnet for extraction purposes is considered, as the magnet has attraction for pieces of shell-casing and rifle bullets, but none for lead. Pieces of lead are generally distinguished from shell-casing by their difference in shape and whiter appearance. When pieces of lead penetrate the cranium, they nearly always shed fragments in the brain track, and these are easily recognized by their white glistening appearance against the darker background (*Fig.* 7).

Pineal Body.—The shadow cast by the pineal body may easily be mistaken for a bone fragment. On several occasions while examining radiographs for lesions, we were puzzled by the presence of a small circumscribed area of density, generally oval in shape, and closely resembling a small flake of bone. Its position was constant, being situated mid-way along a line drawn between two points above and behind the two external auditory meati. To decide the nature of this small body, lead cyphers were fixed to the scalp two inches above the nasion and one inch above the inion. The object lay just above the line joining these two points, and about mid-way along it. Nasion to inion equals 20 cm.; the body was found 11 cm. from the nasion. This is the actual position of the pineal body in the middle line of the skull (from its position Lieutenant-Colonel Gordon Holmes assumed it to be the pineal body). In certain cases where a fracture exists, the presence of this small organ has complicated the diagnosis. We have already collected ten radiographs showing the presence of the pineal body, its visibility being doubtless due to the accumulation of opaque concretions that are liable to form in this organ after adolescence (*Fig.* 1).

Diagnosis of Fractures.—The dark shadow cast by a wound of the scalp, especially when there is considerable loss of tissue, is sometimes mistaken for a fracture; and the lighter markings due to the obstruction caused to the rays by some dressings, especially cyanide gauze, have to be kept in mind.

Sutures.—A fracture in the situation of the sutures may be overlooked, especially if it is small, and running in the same direction. In these instances radiographs should be taken so that there is no overlapping of the corresponding sutures on the two lateral aspects of the skull, and they should give the fullest possible detail.

Doubtful markings in the position of the Wormian bones present difficulties.

FIG. 1.—*Position* 4. Ring on scalp wound: no fracture, and no cranial injury. A. Pineal body, well-marked, opaque, and resembling a foreign body; B. Styloid process and stylohyoid ligament well-marked; C. One condyloid process of occipital is fairly seen.

Fractures in the line of the sagittal suture cannot be always diagnosed if an ordinary lateral view is taken. The shadows of the ridges which go to form the bed of the superior longitudinal sinus overlap, and it is only by taking radiographs in *Position* 3 that they can be separated so as to bring clearly into view the line of the suture.

The lambdoid suture along its whole length requires the minutest inspection to eliminate the possibility of fracture. In the position of the posterior superior and the posterior inferior parietal angles it presents difficulties which sometimes can be only overcome by radiographing in *Position* 4.

Minute fractures in the neighbourhood of the lateral sinus, especially beneath the petrous bone, are liable to be overlooked. Fractures in the

FIG. 2. *Position* 4. Showing the posterior vascular sinuses. Depressed fracture; no penetration of dura. Ring marks the scalp wound, from the posterior extremity of which runs downwards and forward a wavy depressed fracture as far as the anterior missile B. It then passes downward and backward, where it terminates at the lambdoid suture C. Missiles are embedded in the bones. E Well-marked lacunæ; F. Longitudinal sinus, which is seen passing backward and downward to the torcular G., and then outward and finally inward beneath the petrous bone to its termination H. The occipital sinus lies between G and H; H. Foramen magnum.

position of the torcular are easily diagnosed, provided they are taken in *Position* 4 or 5.

It is necessary to draw particular attention to a triangular shadow cast by the tip of the lesser wing of the sphenoid passing upwards and backwards, slightly in front of and parallel to the groove formed in the bone by the middle meningeal artery, as it is often overlapped by the one cast by the

middle meningeal artery where it grooves the anterior and inferior parietal We sometimes have found difficulty in giving a definite diagnosis in this situation.

Blood-Vessels.—In a large number of radiographs the shadows cast by the diploic, meningeal, and other blood-vessels of the brain are clearly shown, and in some cases difficulties have been found in distinguishing them from fractures. We have to take into consideration their length, shape, branchings, their thinning as they travel upwards to the vertex, and their presence on the opposite side of the cranium when the plates are viewed reversed.

Lacunæ due to thinning of the cranium by Pacchionian bodies sometimes require the minutest attention, especially when there are scalp wounds in the neighbourhood (*Fig.* 2).

Experience has shown that with well-prepared plates, carefully examined, it is very rarely that a fracture, however minute, is missed. The following case well exemplifies this point :—

Case 1.—Pte. M. was brought into hospital on Aug. 24, 1916, suffering from a wound of the vertex received the day previously. He exhibited slight sinus symptoms. Examination revealed a dirty gutter-wound stretching across the vertex, 9½ inches behind the nasion (nasion to inion 13½ inches), with bare bone showing. *X* rays showed a minute defect exactly over the sagittal suture, with a large flake of in-driven table under it. Two small metallic fragments were seen lying in the right cerebral hemisphere at a considerable distance from the wound of entry.

Operation was performed on Aug. 25. A flap was turned down, including the wound and a large area surrounding it. No sign of any fracture of the outer table was seen, and the sagittal suture appeared normal. It was thought inadvisable to trephine on account of the dirty nature of the scalp wound, and there seemed to be more than a suspicion that the *x* rays for once had lied. Two days later the patient's temperature suddenly rose to 103°. He became unconscious, the sinus symptoms in his legs progressed, and his left arm, which had previously been normal, became paralyzed. The flap was re-opened : now, over an area the size of a five-shilling piece, surrounding that portion of the sagittal suture where the *x* rays had revealed a deficiency, there was a discoloured patch of outer table. Even then close examination revealed no fracture. A trephine disc was removed just to the right of the unhealthy area, and this latter was removed with forceps as far as possible in one piece. A large flake of inner table was found depressed on to the dura, and there was a small dural defect immediately to the right of the sinus, which bled freely during the course of the operation. A deep brain-track led downwards and to the right in the direction of the shell fragments. Examination of the bone removed suggested that the missile may have entered as one piece and subsequently broken up into two, passing between the lips of the sagittal suture, for no fracture could be discovered.

III. CLASSIFICATION OF THE TYPES OF INJURIES REVEALED BY RADIOGRAPHS IN RESPECT OF THE NEED FOR SURGICAL INTERFERENCE.

1. No fracture to be seen by X rays.—Previous to the introduction of the helmet, these wounds could be safely left without surgical interference, and we never had reason to regret our expectant policy : but lately we have been struck by a remarkable series of cases, about six in number, all wounded on or about the apex of the temporal crest. These patients have come in but little affected, often showing no physical signs, or, at most, a slight facial weakness, paresis of one arm, or some aphasia. Their temperature and general

condition on admission have given no cause for anxiety. They have remained well for two or three days, at the end of which time signs of cerebral mischief have suddenly revealed themselves. Fits unamenable to bromide or morphia, increasing optic neuritis, severe headache progressing to drowsiness, with progression of focal symptoms, have all indicated urgent need for operation. On turning down a flap, at most a slight cracking of the temporal bone has been seen; more commonly there has been a considerable area of discoloration, a bluish appearance of the bone under the wound; in one case there was no change in the bone at all. There has been no extensive extradural hæmorrhage, but the dura has appeared discoloured and unhealthy. Underlying the dura, which was in most cases adherent to the subjacent brain by a layer of altered clot, a considerable cavity containing pulped brain and sanguineous material has been found in the temporal lobe. Evacuation of this collection, with drainage, has caused a gradual amelioration of symptoms, and our mortality for the six cases has been nil. The following case is typical of this class:—

Case 2.—Pte. J. was admitted to hospital on Aug. 9, 1916, suffering from a superficial gutter-wound in the region of the left temporal ridge. He stated that he was wearing a helmet when wounded. He was quite fit and intelligent on admission, but had some slight sensory aphasia. His temperature was normal. *X*-ray examination was entirely negative. He remained well until Aug. 11, when he had a Jacksonian attack, limited to the right side of his face. He also developed weakness of the right side of his face and his right arm during the day, and one fit followed another at rapidly decreasing intervals. His optic discs showed two dioptres of swelling.

Operation was performed on Aug. 11. A large flap including the wound was turned down, and it was then found that the wound was literally only skin-deep, and the underlying fascia had not been penetrated. No injury to the bone was seen. A trephine disc was removed under the wound near the apex of the temporal ridge, and a large area of bone nibbled away with forceps. The underlying dura was tense and discoloured, but had not been penetrated. A small dural flap was turned down. On incising the flap the underlying cortex was found firmly adherent to it, with a thin film of altered, adherent, sticky blood intervening. Underneath was a considerable cavity in the temporal lobe, containing much disintegrated brain substance mixed with sanguineous purulent material. This was evacuated, and the cavity drained through the scalp wound by a rubber tube. The following day the patient was very ill and collapsed, and had several fits, but after that he steadily improved, and has since gone home.

It has seemed to us from a study of the above series of cases that this phenomenon is due to a 'whipping' of the temporal bone, which, unlike the other components of the skull cap, is unprovided with a diploic splint. Consequently considerable damage may be done to the underlying brain, although no fracture is revealed. An important causative agent is also probably the fact that the buffers in the lining of the helmet are in close contact with the head in this region. In other regions where no fracture is shown we have had no such difficulties.

2. **A small bone crack, usually limited in extent, with no sign of in-driven fragments.**—These cases we generally left alone, as it is difficult to see what can be gained by operative interference.

3. **Extensive fissured fractures without depression.**—These are often serious, running down to and involving the base of the skull. We usually left

them alone unless urgent symptoms manifested themselves. It is important to note that the dura is frequently nipped up in the fissure, and may be much damaged at the time of operation unless the fact be borne in mind. Fractures of this nature are generally due to the impact of a large blunt object, such as a big shell fragment or nose cap, on the skull. We believe that skulls showing extensive fissured fracturing have increased in relative proportion to the other types of wounds since the introduction of the steel helmets.

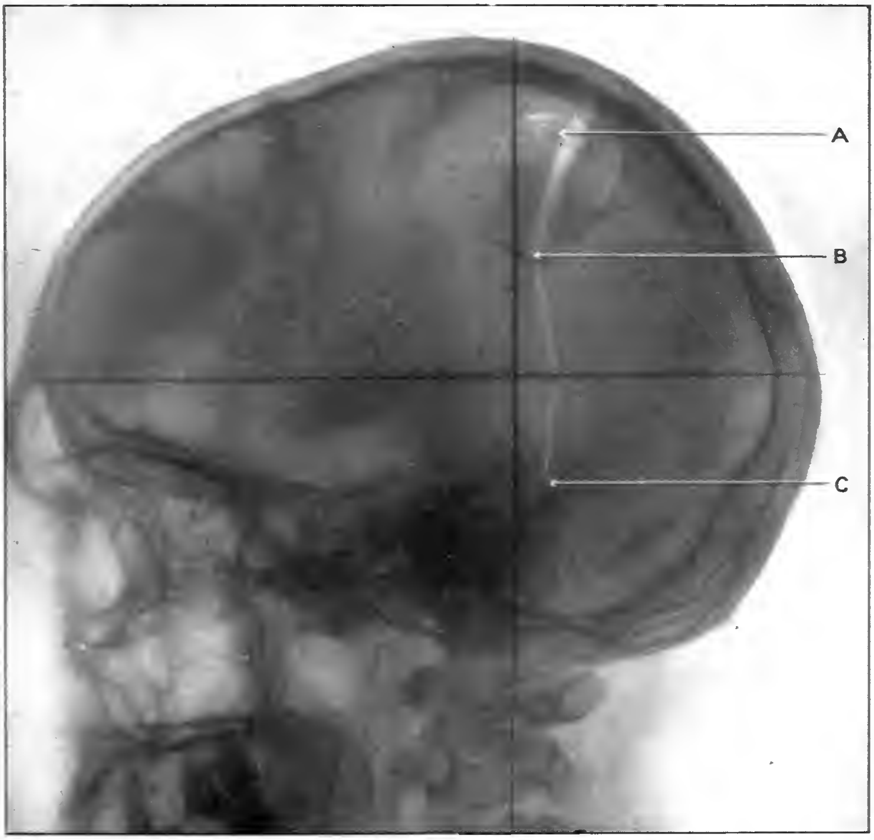

FIG. 3.—Gutter fracture, with limited depression of the inner table and with extensive fissured fracture extending to the base. A. The light area is the actual outline caused by the wound in the scalp; B. Dark circular lines mark the depressed inner table, which does not penetrate the dura. C. Fracture, which can be followed stereoscopically as far as the foramen magnum.

4. **Gutter fracture with only limited depression of the inner table.**—The outer table remains more or less in position. The injury in these cases is only shallow, and often it can be safely prophesied that no injury to the dura beyond bruising has occurred. To this class belong the 'lid-like' fractures, the two lips of the lid being inverted in a valve-like fashion (*Figs.* 2 and 3).

We have made it the usual practice to operate for the removal of these depressed fragments, unless the fracture is over the longitudinal sinus.

5. **Gutter fracture with considerable in-driving of the inner table.**—The brain underlying the fracture is penetrated by bone fragments to a greater or less extent. The contour of the outer table is still more or less preserved. In this class we have operated on every case.

FIG. 4.—*Position* 1. The lobulations of the brain are visible, especially in the frontal convolutions. Two large defects in the skull are shown, caused by multiple wounds. A. Depression to the right of the middle anterior frontal. Metal in scalp; no metal in brain, but a track passing inwards for 2½ inches; B. Linear fracture passes backward as far as posterior parietal; C. Large depressed fracture to the right and below the torcular; D. Metal in wound entrance; E. External auditory foramen; L. Lambdoid suture resembling a fracture.

6. **Penetrating wounds with no missile in the brain** (*Fig.* 4).—In this class there is a definite defect involving both tables. Fragments of bone are driven into the brain to varying depths. Such cases almost invariably require operative interference, and generally at the operation a dirty brain-

track is found containing bone fragments and pulped septic brain material. The chances of the patient's recovery seem to vary inversely with the length of the track, those communicating directly with the lateral ventricle being very fatal. Penetrating wounds below the tentorium cerebelli are also of bad prognosis (*Fig.* 5).

FIG. 5.—*Position* 4. Multiple injuries. Ring over wound in left mid-parietal area. Defect in skull, with track passing into brain for a distance of over an inch. A. Fracture passing directly forwards to anterior frontal; B. Large second wound and bony defect in right occipital, just above and to the outer side of the torcular C; D. Large piece of shell, which has passed through the occipital wound, tunnelled the base of the skull, and emerged at the level of the base of mastoid and to its inner side; E. Marks the exit. The lateral sinus was opened up. The lambdoid suture is well seen.

7. Wounds with one or more missiles retained, either in the bones of the skull or in the brain.—

a. The missile may actually be arrested in the bone.

In some cases the projectile has penetrated the outer table only, leaving the inner table intact. A trephine disc has been removed, comprising the outer table, with the missile firmly stuck into it, leaving the inner table and

a great part of the diploe intact. Both tables may be penetrated, a part of the missile lying firmly wedged in the bone. In one case the foreign body, a thin sickle-shaped fragment of helmet an inch in length, had penetrated both tables. Its lower end was driven through the dura for fully a third of an inch, while its upper end just protruded above the outer table.

b. The missile may have passed entirely through both tables of the skull, and be lying between the inner surface of the skull and the dura, the dura still being intact.

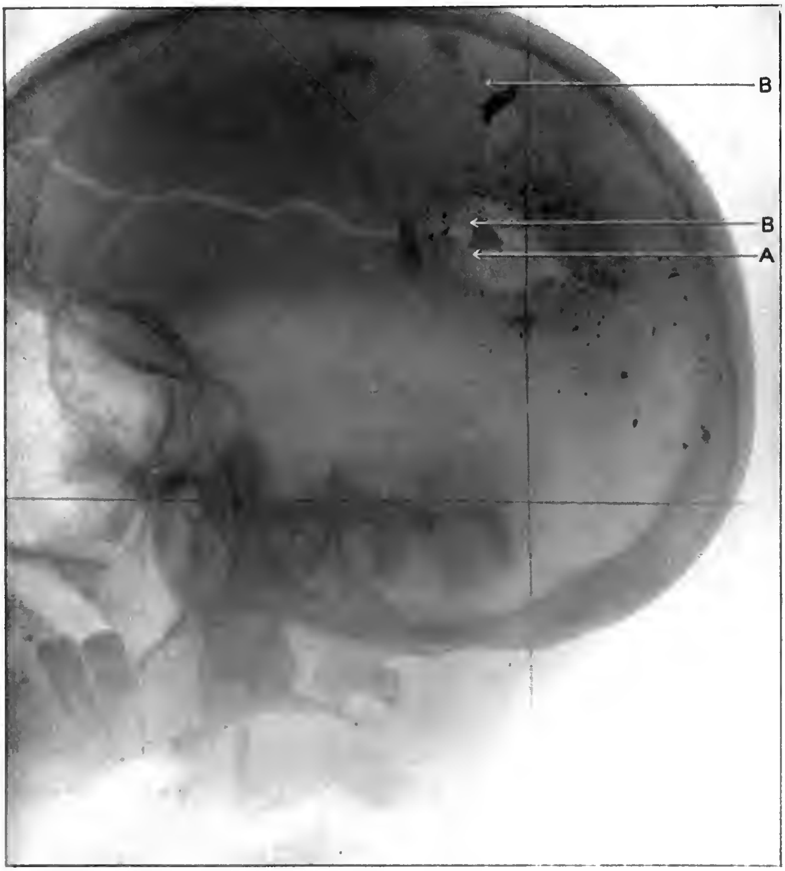

Fig. 6.—*Position* 2. Pte. C., admitted April 19, 1916, died the same day. A A large circular defect in the right posterior parietal region. Edges of defect are lined by numerous small metal fragments. All the larger fragments are in the wound track crossing the brain almost to the other side of the skull; B. Shows the largest fragments, all of which are furthest removed from the wound of entry. Extensive fissured fractures extend horizontally forwards to the frontal region and backwards to the upper occipital.

We have had a number of cases of this variety, and have operated on every one, with no mortality. In certain cases the missile has penetrated the dura and has sprung back, lying between it and the inner aspect of the skull.

In several cases in which this has happened the brain has become infected underneath, and the missile has been found at the operation to have formed the cork to a large brain abscess.

c. One or more missiles may be lying in the brain substance at varying depths from the wound of entry.

The missile usually forms the base of a cone, the apex of which is at the wound of entry into the brain. This cone is made up of pulped brain tissue and bone fragments of varying sizes. In those cases where the missile is made

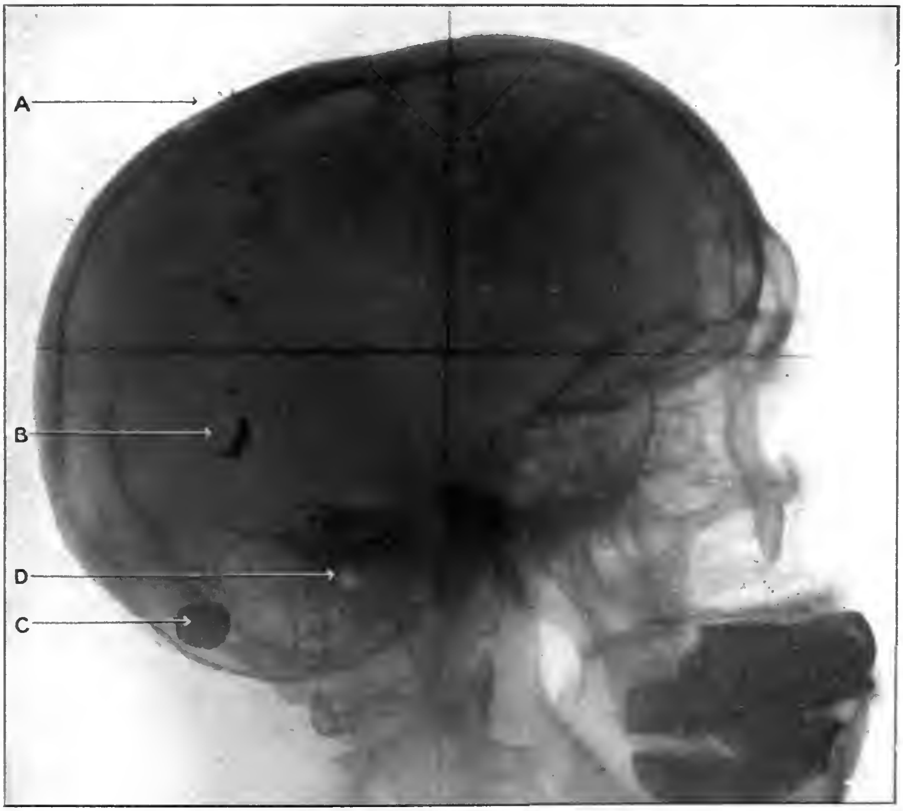

FIG. 7.—*Position* 4. A. Wound of entry of shrapnel ball just to the left of the vertex, where some small metallic fragments may be seen lying in the scalp; B. Downward track showing lead shavings in the brain; C. A large misshapen ball lying in the left cerebral hemisphere; D. Auditory meatus.

of lead, say a shrapnel ball, small shreds of the outer covering of the ball are shed along the track, and may be seen as glistening white specks (*Fig.* 7). As a result of this 'moulting' process, the ball itself may be very much misshapen. It is interesting to note that the larger bone fragments lie at a greater distance from the wound of entry, and consequently nearer the missile, than do the smaller, and it is quite the exception to find any of these at a greater depth

than the missile. Often, if one of the larger of these bony fragments be lying turned on edge, the shadow cast by it approximates to that cast by a small piece of metal, and it may be difficult to determine which of the two it is. The importance of determining whether any missile be of lead or some other metal is apparent when the question of its possible removal by a magnetic rod comes to be discussed. (See *Figs.* 6 and 7.)

We have come across several instances where the missile had penetrated the brain, and lay on or near the bone on the opposite side of the cranium. The foreign body retained is generally a large piece of iron casing; in some instances fractures of the bone were found near the position of the foreign body, showing the position where the missile had struck the bone, but its momentum was not sufficiently great for it to penetrate and pass onwards,

Various Types of Missiles met with.—In the early days, during the first and second battles of Ypres, we passed through a phase when many shrapnel balls were retained in the skull, our record case being one in which five such balls were embedded in one brain; but lately, since the almost universal adoption of high-explosive shells, these have been seen but rarely.

Rifle bullets are comparatively seldom seen, but during the past year we have had several such cases. The wound of entry caused by a rifle bullet is often small and easily missed, and commonly no bone defect can be felt. The patient is often surprisingly well, and in at least one case it was only by chance that an *x*-ray photograph came to be taken.

Case 3 (*Fig.* 8).—Gunner C. was admitted into hospital on July 1, 1916. He was wounded on the night of June 30. There was a fight between two aeroplanes going on overhead. He was wearing no helmet, and thought that he had been struck by a shell fragment from an anti-aircraft gun. He had a tiny wound of the vertex 5 inches behind the nasion (nasion to inion 14 inches) and $\frac{3}{4}$ inch to the right of the mid-line. There was some œdema around the wound. *X* rays showed a small opening in the skull under the wound of entry, with a brain-track passing down to the base of the skull, where lay a rifle bullet behind the right orbit. The apex of the bullet was sticking into the hard palate. Beyond a slight frontal headache and some drowsiness on admission he had no physical signs, and was evacuated to England on July 14, no operation having been performed.

Nowadays shell fragments form by far the greatest proportion of missiles; commonly there are one or two, but in some cases, mostly hopeless, we have seen dozens of such fragments embedded in the brain (see *Fig.* 6).

Operative Treatment.—Whilst tempted, in the early days, to operate on every case, and attempt removal of the missile if not too hopelessly inaccessible, lately we have adopted much more expectant treatment. If the missile be deep and the wound of entry clean, we have left it untouched unless urgent symptoms arise. The following is a good example of the small amount of damage that a number of missiles embedded in the brain may do.

Case 4.—Pte. T. was admitted to this hospital on June 17, 1916, suffering from a grazed wound of the frontal region, evidently only superficial. He gave a history of having been wounded the previous March by a rifle grenade at the back of the head. This wound must have caused him little trouble, for he was back with his regiment nine days later. After rejoining he noticed a difficulty in controlling himself, becoming easily excited when in the fire trenches. He had been discharged from the army in 1906 for insanity, and was put into a lunatic asylum for some time by his own people. He also had a bad family history of insanity. It is not to be

wondered at, therefore, that he became excited while under fire, and his wound probably had little to do with the condition. He was also gassed on April 29, but not sufficiently badly to leave his unit.

Examination of his head revealed the recent graze over the frontal region, and a tiny, perfectly healed wound of the occipital region 1 inch above and 3 inches to the right of the inion. X rays showed no fracture under the recent frontal wound, but a small defect of the occipital bone under the old wound, with a shell fragment and many small pieces of bone embedded in the right occipital lobe. He seemed normal in every way, and showed no sign of intracranial injury. He was evacuated to England on June 20, apparently quite well.

FIG. 8.—*Position* 1. Gunner C. (*Case* 3.) A. Marks a tiny perforation of the skull near the vertex. From this a bullet has passed through the brain and the base of the skull just behind the right orbit, and is lying with the apex embedded in the hard palate. The track of the bullet is very faintly shown.

When the wound of entry is septic, and especially if pulped brain be oozing from it, operative interference of some sort is imperative. Where the foreign body is inaccessible, two inches or more from the opening in the dura, it has been found advisable to do nothing more than clean up the wound of

entry, removing the superficial in-driven bone fragments, and if the track be not too hopelessly septic, drain by lateral rubber tubes placed in at the angles of the flap after excision and suture of the excised edges of the wound of entry. We have resorted to direct drainage of the track through the wound of entry for the most part only when we have judged it to be very septic.

FIG. 9.—*Position* 1. (*Case* 5.) Wound track through brain distended by infection with gas-forming organisms. A. Point of entrance; B. Small fragment of shell lying in end of track underneath pia mater. The large main track runs directly through the left cerebral hemisphere, and is much larger than the entering missile. Its wavy appearance is caused by side pockets of gas contained in tracks which pass laterally; C. A tiny fragment slightly above the pituitary gland lying at the end of a track which passes in a crescent direction downwards and forwards from about the middle of the main track. The patient survived for five days after this radiogram was taken.

In one extraordinary case (*Case* 5) we were able to show by x rays a brain-track giving a peculiar wavy appearance, due, as autopsy subsequently revealed, to a gross infection of the track with gas-forming bacilli.

Case 5.—Pte. R. was admitted to hospital on May 22, 1916, suffering from a wound received on May 17. He brought a note down with him from the casualty

Fig. 10.—(*Case* 6.) There is direct bruising of the scalp around the entry-wound over the right frontal region. The hæmorrhage around the eyes has been extravasated from bleeding within the anterior fossa. The forehead is deformed by the uplifted fragment of the frontal bone.

clearing station saying that a decompression operation had been performed around the wound of entry on May 19. He had a deep gaping elliptical wound, 11½ inches behind the nasion (nasion to inion 13 inches) and 2½ inches to the left of the mid-line. The brain was exposed at the bottom of the wound.

X-ray examination (*Fig.* 9) revealed a large bone defect in the left occipital region, with a small shell fragment just inside the opening. From this an extensive wavy track passed forward to the frontal region, where lay a shell fragment small out of all proportion to the very large track along which it had passed. From the

Fig. 11.—*Position* 1. (*Case* 6.) Perforating wound of frontal region, showing large 'expressed' fragments of frontal bone, comprising both tables, between the wounds of exit and entry. The ring marks wound of entry.

centre of the main track a subsidiary track passed downward, forward, and inward, terminating in the region of the pituitary fossa, where there lay another small fragment of metal. A tentative diagnosis of gas-gangrene infection of the track was made, to account for this unusual appearance. The patient was comatose on admission, and died a week later. Autopsy revealed a very extensive brain-track, showing obvious gas-gangrene infection, passing forward in a manner shown in the radiograph.

8. **Perforating wounds, with entry and exit wounds present in the skull** (*Fig.* 5).—Wounds of this type have been comparatively rare, especially since the universal adoption of the helmet by our troops, but a certain number have passed through our hands.

Biparietal perforating wounds, usually caused by a rifle bullet, have perhaps been the most common examples of this type, and often in the cases that arrive here, surprisingly little damage appears to have been done to the bone or brain. In one case, Pte. M., a detailed report of which has already been published,* a shrapnel ball had passed through the brain from one parietal region to the other, and was found by x rays to be lying between the temporal muscles and the bone on the side opposite to that by which it had entered. Beyond slight apraxic symptoms the patient seemed little the worse for his injury, and was able to walk a few weeks later. We have heard with regret that this patient has since died after a secondary operation for removal of bone fragments.

Perforating wounds of the frontal region have usually been very severe, the frontal bone being very extensively fractured and broken up, with great destruction of the underlying frontal lobes.

Case 6 (*Fig.* 10).—Pte. A. was admitted on Aug. 22, 1916, suffering from a rifle-bullet wound of the frontal region received on Aug. 16. He was wearing a helmet, and the bullet must have traversed the helmet. He was unconscious for a time, but recovered sufficiently to walk from the trench where he was wounded to the dressing station. The wounds of exit and entry are well shown in the figure. There was much bruising and discoloration over the whole area included between and surrounding these two wounds, and the whole scalp appeared uplifted in this region, giving the patient an appearance uncommonly like that presented by a case of congenital 'tower-skull'. There was also much bruising and discoloration around both eyes, but no proptosis.

X rays (*Fig.* 11) showed a large plate of the frontal bone uplifted between the wounds of entry and exit ; from this a linear fracture passed back to the region of the right coronal suture. There were no bone fragments driven into the brain. His only symptoms were some drowsiness and severe frontal headache. During the first few days after admission his condition gave rise to anxiety, and the bruising and discoloration increased to an extent we had not hitherto seen. After the first week, however, he improved, the bruising subsided, and an x-ray photograph taken just before discharge to England on Sept. 8, showed the displaced plate of the frontal bone beginning to drop into position again.

Although great bruising around the eyes, indicating a fracture into the anterior fossa, has always been common in frontal injuries, it is only lately, since the introduction of the helmet, that cases showing severe mottling of the scalp, usually of a purplish tinge, have appeared. In the above case it was probably due to squeezing of the scalp tissues between the uplifted bone and the under surface of the non-yielding helmet.

Perforating wounds of the occipital region have been rarely seen, doubtless on account of their early fatality.

We wish to express our indebtedness to the Medical Research Committee for the use of the coloured plate.

* SMITH AND HOLMES, "A Case of Bilateral Motor Apraxia with Disturbance of Visual Orientation," *Brit. Med. Jour.*, 1916, March 25.

REPAIR OF INJURIES TO THE SKULL BY PERFORATED PLATES.

By A. B. MITCHELL, Belfast.

Head injuries in the war are so numerous and so serious in their sequelæ that any means of minimizing their ill effects must be worthy of consideration. For some time past I have been in the habit of repairing gaps in the skull by the use of very thin perforated silver plates.

The silver is rolled out a little thinner than an ordinary visiting card, and is then punched with holes one-eighth of an inch in diameter, as close together as possible. This has the following advantages:—

1. Being very thin the plate can be readily adapted to the convexity of the skull.

2. The perforations have the advantages that they lighten the plate; they admit of the escape of blood or other fluid, so as to avoid compression by accumulation between the plate and the dura or brain; and they provide a simple means of fixing the plate in position.

Technique of Operation.—The plate, which can be cut to any required size by strong scissors, is applied as follows:—

1. A large flap of scalp is turned down.

2. The opening in the skull is explored, any foreign body is removed, adhesions are freed, and bleeding is arrested.

3. The periosteum is now carefully raised from the skull for about half an inch all round the gap.

4. The plate, cut the necessary size and shape (half an inch in diameter larger than the opening it is desired to close), is now slipped under the reflected periosteum and fixed in position by a series of catgut sutures which, by the aid of a fully-curved needle, are carried through the periosteum and out through any of the perforations in the plate which are most convenient. In this way the plate is securely fixed in position and cannot slip. The scalp flap is now sutured in position, and a drainage tube inserted at the most dependent angle for twenty-four hours—otherwise a hæmatoma is very likely to form.

Needless to say the most rigid asepsis must be observed.

The following case illustrates the benefits of this operation:—

Bullet Wound over Left Motor Area.

I. O. R., age 20, was wounded August 26, 1914. The bullet, which was found on the cortex of the brain, was removed at a French hospital. His right side at that time was completely paralyzed. He gradually improved, and at the end of fifteen weeks was able to stand on the right leg, and ultimately regained almost complete power over his right side. In January, 1915, he began to have typical Jacksonian fits, commencing in the right foot and spreading to the right arm and face. When admitted to my ward in the Royal Victoria Hospital, May 5, 1915, he was having as many as fourteen fits per day. He had a crucial scar and a depression about the size of a penny over the left motor area.

When the scalp was reflected we found a cyst about the size of a hazel nut on the cortex of the brain, in the centre of which was a small irregular piece of bone. This was removed, and the gap in the skull repaired by a perforated plate as described above.

He had a fit the evening after operation, but has had no recurrence since that date. He is now (Dec. 16, 1916) at work and in good health, nineteen months after operation. A radiogram, taken by Dr. Rankin two months after operation, showed the plate still in position.

The largest plate I have yet applied was 4½ inches by 2½ inches. The patient, who was under the care of Dr. St. George in the County Infirmary, Lisburn, was injured by shrapnel on April 13, 1915. At the time of operation, Dec. 14, 1915, he was a confirmed epileptic. He had a large scar on the right fronto-parietal region, just in front of the motor area. This scar was depressed, adherent to the brain, pulsated freely, and was very tender.

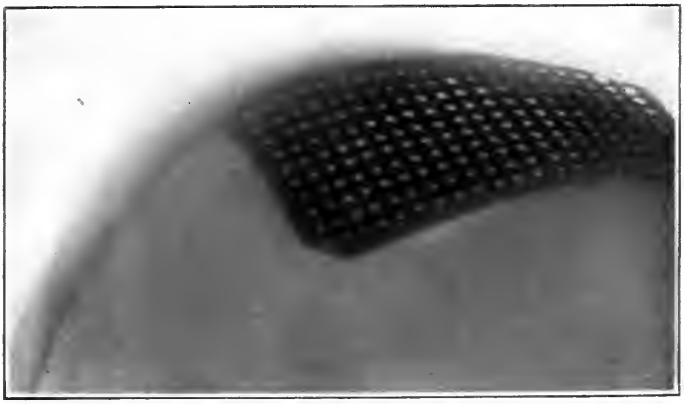

FIG. 12.—Radiogram showing perforated silver plate in position on the skull five months after operation

With the assistance of Dr. St. George, the skull was plated on April 13, 1916. The accompanying radiogram, kindly taken by Dr. Rankin on Sept. 22, shows the plate in position five months after operation (*Fig.* 12). He still has some fits, but they are not nearly so frequent or so severe as before operation.

I have now operated on six of these cases. In every instance primary union was obtained, and marked relief followed the operation. None of the plates gave rise to any trouble.

THE REPARATION OF CRANIAL DEFECTS BY MEANS OF CARTILAGINOUS GRAFTS.

By H. L. WARREN WOODROFFE, Lyon, France,
Surgeon to the Ulster Volunteer Hospital.

The problem of the reparation of cranial defects has latterly become one of extreme importance. Before the War it was, on the whole, rare to find cases in which large gaps had to be left in the skull, except where decompression was performed for increased intracranial tension, when it was obviously to the patient's advantage that the opening should remain patent. Now, we see on every hand cases of fractured skull, and they are nearly always accompanied at first by septic infection of the brain and meninges; a fact which renders free removal of bone an imperative necessity, both for purposes of drainage, and for relief of the temporarily increased cerebral tension. Hence, not only is trephining a far more common operation than formerly, but with increased experience large openings have become more and more the rule, and this in men to whom a permanent cranial defect can be no possible benefit.

There are many cases of trephining in which no reparative operation is advisable: the small trephine hole, made for a fissured fracture, and revealing an intact dura mater, has long been known to cause no trouble. But we do not very often have to deal with such cases in military surgery. Where the breach is large, as it usually is, the question of reparative operation is always to be considered.

The position of the gap also makes a difference in the symptoms caused. When it is opposite the attachment of the falx cerebri or tentorium cerebelli there are rarely any symptoms of importance, so much is the dura strengthened from within. One might indeed say (physiologically speaking) that in such cases one has to deal with two small openings rather than one large one. But the possibility of one of the great sinuses being involved in any subsequent injury to the defenceless spot must be kept in view. Wounds of the squamous temporal bone are protected by the temporal muscle and fascia, unless these are too much destroyed. But where the frontal, the parietal, or the occipital bone (above the superior curved line) is affected, it is the rule and not the exception to find symptoms of unstable intracranial equilibrium.

What then are the signs and symptoms which should lead a surgeon to advise operation in these cases? It is not always easy to know how far symptoms should be attributed to the cranial lesion, and how far to some underlying cerebral condition. It is therefore well to assure oneself that there is no foreign body lying overlooked in the brain and really causing the trouble; should such be found, its removal (if practicable) is the logical prelude to any attempt at repair of the skull.

The two most important signs—they always go together—pointing to a

seriously weakened state of the cerebral defences, are visible pulsation, and impulse on coughing. In severe cases a definite bulge may even be seen on the occasion of any quick movement. The presence of these signs may depend on the size of the hole, on its position, on the state of the underlying dura, or on all of these together. Whatever the cause, they indicate that the equilibrium of the brain is affected, that any movement jars the delicate cortical tissue against the unyielding edges of the aperture, and that a state of affairs is present which calls for remedy.

The symptoms most complained of are headache, vertigo, and sudden blurring of the vision. Though these are common symptoms of cranial and intracranial trouble, they may fairly be laid to the charge of the cranial defect when they are brought on by sudden movement. Inability to sleep, except with the head raised or tightly bandaged, and objection to noise, are also complained of. These symptoms can often be cured by a cranioplasty. We see also cases where the patient complains of pain and giddiness when the slightest pressure is applied to the affected spot; or where he is obsessed by the fear that any blow will result in sudden death, and begs for a protective apparatus. The value of such apparatus is very doubtful. It may be useful against outside injury, but it cannot protect the brain from constant traumatism against the edges of the gap; in any case the constant wearing of a tightly-fitting head covering is wearisome, and the result desired is far better obtained by an operation which secures a permanent and physiological protection.

It is doubtful whether unstable intracranial equilibrium alone is a frequent cause of Jacksonian epilepsy. But in any such case of epilepsy operation is advisable, with a view to the discovery and removal of the cause; and if at the same time the defect can be closed without any great increase of the shock and risk of the operation, there is no reason to refrain from so doing. There are cases on record where no cause for the epilepsy other than the cranial breach was found, and where the mere reparation of the skull has effected a cure.

Finally, and an important point in frontal wounds, the cosmetic result must be considered. A depressed, discoloured scar on the forehead is an unsightly thing; its removal is in itself well worth an operation—certainly many are performed for as little or less.

Contra-indications of the Operation.—These come under two headings: (1) General; and (2) Local.

1. The former are those which have to be taken into account in the case of any operation of expediency. No surgeon of course would operate, except in a case of extreme urgency, on a diabetic, a consumptive, or a man with advanced heart disease or Bright's disease. But such cases rarely come into the sphere of military surgery, and it is with this branch that we are mainly concerned. Bronchitis is a contra-indication: where any cough causes a cerebral impulse, frequent coughing would tend to displace any material used to fill a gap in the skull; moreover, in the case of the operation we propose to describe, where the grafts are taken from the lower costal cartilages coughing is painful in the extreme during the first few days after operation.

So, if any bronchitis be present, measures should be taken to cure it before proceeding to a reparation.

2. The local contra-indications are two: One should not operate while there is anything present to favour sepsis—that is to say, not until the wound has healed and the last scab dropped off. Nor should one repair the cranial gap while there is any marked bulging or any sign of increased intracranial tension. The mere size of the gap is no contra-indication, except in so far as some are too small to be worth repairing; no gap compatible with life is too large to be repaired, and the larger the gap the greater the need for repair.

Forms of Operation.—Many are suggested. Following Mauclaire, we may classify them thus:—

1. *Periosteal, Osteo-periosteal, and Cutaneo-osteo-periosteal Cranioplasty.*—These operations, to be efficient, involve the removal of part of the outer table of the skull adjoining the breach. This is a matter of some difficulty, with considerable shock, and necessitates the use of expensive apparatus such as an Albee's bone set.

2. *Bone grafts.*—These may be autoplastic, making use of the ribs (Kahle), great trochanter (Mauclaire), scapula (Leclerc), or tibia (Delagenière); these are all operations of some magnitude, and involve a considerable waiting period. The use of homoplastic grafts is limited by the difficulty of finding a suitable subject to take them from. Heterogenous grafts may be used—for example, the bone of a dog (Macewen, Ricard)—but these are open to the same objections as all heterogenous work.

3. *Sterilized decalcified bone* may be used.

4. *Prosthetic methods*, such as the use of plates of gold (Estor) or ivory (Mauclaire).—These may give excellent results, but they are open to the objection urged against the introduction into the tissues of any non-absorbable foreign substance—that it may, and often does, come to act as an irritant. While this does not matter much in the case of a bone plate which can be removed when its work is done, it is a serious thing when the removal of the foreign substance would undo all the work of the operation.

5. *Cranioplasty by means of cartilaginous grafts.*—This is to our mind the best and most universally applicable of all. It is at once safe and simple, and the shock is minimal; the grafts are autoplastic.

The operation, first described by Morestin in February, 1916, consists briefly in the filling of the gap with grafts taken from the lower costal cartilages. It was brought to our notice by M. Villandre, of Lyon, who is responsible for some notable improvements in the technique. The advantages are as follows:—

i. The grafts are autogenous.

ii. The shock to the patient is very small, the suffering entailed is not great, and the risk in suitable cases is practically nil.

iii. The object is rapidly attained: most patients leave hospital with a solid skull at the end of a month or five weeks.

iv. There is no need to wait, as in the case of bone grafts, for several months after the wound has healed before proceeding to operation; the cartilage appears to possess a power, unknown to bone grafts, of resisting

infection. Villandre reports a case where, in spite of a mild suppuration, the grafts survived and solidified. We have operated on more than one case less than a week after the last crusts had separated, and had no reason to regret it. Villandre repaired thirty-two out of his first sixty-four cases less than four months after the injury was received. This is a point of great importance in military surgery.

v. The operation is not a difficult one, and requires no special plant.

vi. In frontal cases it gives an opportunity for moulding, and readily allows of cosmetic results only obtained with difficulty by other methods.

TECHNIQUE OF THE OPERATION.

Preparation of the Patient.—The entire scalp is shaved, and the eyebrows if necessary, as are the chest and upper abdomen. The skin of the operation areas is disinfected with iodine, and surrounded with sterile towels (those over the chest should be covered with another until such time as the grafts are to be cut). A screen is absolutely necessary between the anæsthetist and surgeon, and attached to the patient's forehead, not only for asepsis, but to serve as a point of attachment for hæmostatic forceps used to retract the skin flaps.

The Anæsthetic.—The anæsthetist works under difficulties, so if possible some dosimetric apparatus should be used. Whether chloroform or ether be employed does not seem to matter. Deep anæsthesia is only necessary when cutting the grafts. In France, regional anæsthesia is often used; but though this abolishes the otherwise necessary proximity of operator and anæsthetist, it is not to be recommended; very thorough anæsthetizing of several intercostal nerves (the 5th to the 9th) is necessary. The operation offers a field for the rectal administration of ether, to which we propose to give a trial.

The Skin Incision and Resection of Fibrous Tissue.—The area of the wound is most frequently found occupied by fibrous tissue, which, if on the forehead, is very disfiguring, and in any case gives an insecure hold to stitches. The incision should therefore allow for a free resection of this, and should leave at least a sixteenth of an inch of healthy skin to be resected along with it. From the periphery of this wound cuts may be made as desired, if more room be needed. If the original wound has been sutured, and there is no cicatricial tissue to be excised, one should keep to the old line.

The classical horseshoe flap should not be used, for it is apt to leave a pocket which encourages the formation of a hæmatoma (see *Case* 2). Indeed, if the original incision has been a horseshoe one, it is best to discard it (except on the forehead, when for cosmetic reasons it must be adhered to), and make a crucial incision with the cross over the middle of the hole, giving four triangular flaps. An exception to this rule is in wounds involving the temporal muscle—the splitting of which barely gives room to work—when it is best to turn down a flap. The flaps thus marked out are carefully dissected back until the whole of the cranial gap is felt to be exposed. The plane of dissection is the sub-aponeurotic layer; if this be carefully adhered to, it is easy to bring the skin edges together later, and compensate without undue tension for quite large cicatricial areas (see *Figs.* 16, 17).

We now proceed to the excision of the island of scar tissue left in the middle. Here one must work with the greatest care, remembering that the dura has probably been injured and may only be represented by a thin layer of fibrous tissue. The plane of dissection should therefore be kept close to the surface. Should there be an escape of cerebrospinal fluid, the rent should at once be sutured: if this be impossible owing to the friability of the tissues, a muscular or fascial graft should be used.

The Cleaning of the Edges of the Gap.—The pericranium is incised with the point of the knife, keeping as close as possible to the edge of the gap. This must be done with great care, as a slip might have disastrous consequences. Bleeding is usually so free as to obscure the vision, and the work has to be done by touch. When completed, the edges of the aperture are carefully cleared with a rugine. This must be done thoroughly, right down to the dura, and the surgeon must not be satisfied until he can sweep the edge of the rugine round between the deep surface of the skull and the dura mater (*Fig.* 13).

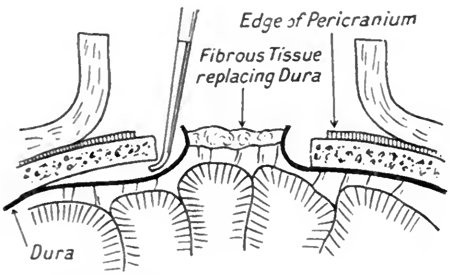

Fig. 13.—Diagram to show the clearing of the margins of the bone opening, including the separation of the dura on the deep surface.

Should this step be inadequately carried out, a projecting spine may be missed on the deep edge of the hole, which might cause epilepsy by pressing on the brain. All roughnesses or projections are removed with a gouge forceps. Any slight cerebral hernia present now falls back, or can be gently pressed into place (the operation should not be undertaken in the presence of more than a very slight degree of hernia).

The surgeon is now faced by a clean hole in the skull, displaying a mass of fibrous tissue with slightly raised edges. It is an easy matter to scrape this mass away with a curette, but it should not be done. To begin with, the dura may be non-existent, and such a proceeding would only open up the sub-arachnoid space. Even if this complication be avoided, there is very free oozing: in two cases (*Cases* 3 and 4) we ascribe the formation of a hæmatoma to our having taken this step. Should there be too much fibrous tissue, it is better to clip it away with scissors; but even this is not necessary. The fear at first experienced of piling on too much tissue, and causing pressure, is unfounded; the real difficulty is to avoid recession of the grafts, with subsequent depression.

If the dura is to be opened, it should be done at this stage; but this is rarely necessary, and should only be done when there is some definite indication of underlying mischief. A swab wrung out of peroxide of hydrogen (to stop the oozing) is placed in the wound, the flaps are turned back over it, and the head is covered with a sterile towel. If any bleeding points are found when the wound is reopened later, they can then be dealt with by under-running.

The Cutting of the Cartilaginous Grafts.—These are taken from the 6th, 7th, and 8th costal cartilages, and should for convenience be cut from

the same side as the head wound. The usual incision is one parallel to and a little above the costal margin. After our first three cases, however, we adopted a vertical one, two finger-breadths outside the edge of the sternum. This gives equally good access; can more easily be extended if necessary: the hæmorrhage is less; and it has the great advantage of splitting instead of cutting across the upper fibres of the rectus.

The cartilages having been thus exposed, shavings are taken of about half their thickness. Care should be taken not to cut through the entire thickness of a fixed cartilage; but the whole tip of a floating one may be taken. It is well to take what seems to be considerably more than enough cartilage to fill the gap. Each graft, as cut, is dropped into warm saline solution.

To facilitate this work at the bottom of a hole, M. Villandre has devised an ingenious knife, the blade of which is set on a shank, bayonet-wise (*Fig.* 14). This enables the grafts to be cut evenly by keeping the blade of the knife flat.

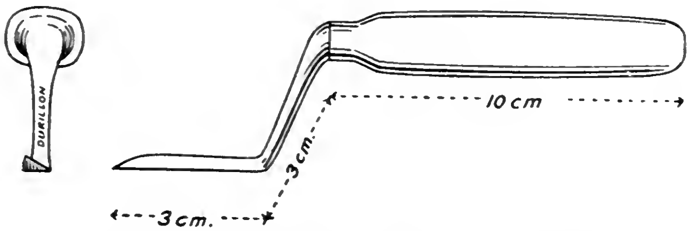

FIG. 14. Knife with shank set at an angle for cutting grafts from the costal cartilages. Designed by M. Villandre.

In operations on the occipital region, this stage must be carried out first, and the wound sutured before turning the patient to incise the head; otherwise it is best to pack the wound with gauze, and proceed at once to transfer the grafts.

Placing the Grafts.—The chief difficulty is to keep these from slipping. To this end it has been proposed to push the edge of the graft between the skull and the dura; theoretically, this might cause a rise of intracranial pressure; practically, the edge of the skull is bound to show as a ridge. It has also been suggested to groove the diploë with a chisel, and push the grafts into the groove, a step which would certainly prolong the operation and increase the shock.

A very simple and rapid method is that of Villandre. One end of a fine catgut stitch is passed through the pericranium, and tied. It is then passed through the pericranium on the other side of the gap, and taken backwards and forwards in a zigzag manner till the hole is covered in with a trellis. In the case of a very large gap it is wise to supplement this network by a second, at right angles to it, and to insinuate the grafts between the two layers. We have now a small chamber bounded by the dura, the edges of the skull, and our trellis, into which the grafts can be slipped with a forceps (*Fig.* 15). It is advised to apply the perichondral surface to the dura, in order to avoid adhesions; in any case it is easier, as the grafts curl when

cut, the perichondrium being in the concavity. They should overlap everywhere, and may well be doubled, as some slight recession always takes place, and those cases give the best final result which, at the end of the operation, show a slight boss. When the frontal or temporal regions are involved, it is well carefully to study the sound side before operating; it is then possible to restore almost exactly the symmetry of the forehead.

Suture of the Wounds.—In this step great care must be exercised to obtain as perfect a scar as possible. If hæmostatic forceps are left on till the wound is to be closed, ligature of vessels is rarely necessary. To get perfect apposition it is well to put one or two mattress sutures in each limb of the incision, supplemented by a continuous blanket stitch, or (in the case of the forehead) by interrupted sutures of horsehair on a round needle. Where the cosmetic effect is of importance, it is advisable to begin the suture at the most invisible end of the wound. We have found it well to leave a silkworm-gut drain in the posterior corner of the wound. The thoracic wound is closed in layers. Time can be saved by the assistant doing this while the surgeon sews up the head.

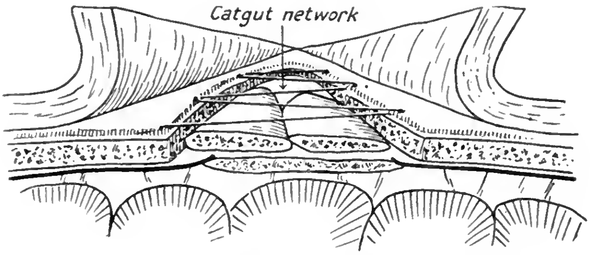

FIG. 15.—Diagram showing cartilaginous grafts inserted between trellis and dura mater.

After-Treatment.—A hypodermic injection of morphine and atropine is given as soon as the patient begins to recover consciousness. This may have to be repeated, as the pain in the thoracic wound is at first acute. The head is inspected on the second day, and the drain removed. The stitches may be removed at the end of the week, when the patient is generally allowed up. At the end of a fortnight the skull is usually hard, though slightly elastic, and all dressings may be discontinued.

RESULTS.

It is necessary to be quite clear as to what the surgeon intends to achieve when he performs a cranioplasty. It is not possible to remove troubles due to brain lesions, but only to protect the brain from further injury, especially from repeated slight trauma due to continual impact against the edge of the breach. He must, therefore, before operating, make up his mind what symptoms really are due to the cranial defects, so as to be able to explain to the patient how much relief he may expect. Viewed from this standpoint, the results are very satisfactory. It is usual to find that the headache is less, that the patient suffers less from noise, and can make efforts previously

impossible; not infrequently he can bend forward quickly without any vertigo. These events do not come immediately, nor even as soon as the grafts have solidified; but at the end of about six weeks considerable improvement is usually shown.

A few statistics may be helpful: Gosset, in May, 1916, reports 32 cases, with 2 deaths (from bronchopneumonia) and 30 successes; Villandre, in October, 1916, 64 cases, with 63 successes. These observers probably count their successes from the point of view of the solidification of the breach. Marie, in reporting on 21 cases in which mechanical success was achieved, notes 6 improved as regards symptoms, 12 stationary, and 3 aggravated. This is probably an unfortunate experience. Of the 7 cases operated upon in the Ulster Volunteer Hospital, 6 have shown definite improvement in the symptoms, while all 7 have solid skulls.

As regards the military fate of the patients, very few are able to go back to the front; it is found that the strain and noise bring on a return of the symptoms. Most of them, however—in fact, practically all who have not sustained some deeper injury—are, at the end of a few months, fit to do useful work in the auxiliary services.

The ultimate fate of the grafts has not yet been decided. Only time and the x rays can show whether they remain cartilaginous, or ossify. So far, radiograms taken at the end of some months tend to uphold the former view. Sicard was obliged, because of return of the symptoms, to remove a graft at the end of four months. He found no sign of ossification, or even of calcification. The line of demarcation between bone and cartilage was perfectly clear, the two being firmly fixed together by fibrous tissue.

NOTES OF SEVEN CASES OPERATED UPON IN THE ULSTER VOLUNTEER HOSPITAL.

Case 1.—Soldat F. G. Wounded on May 19, 1916, in the left frontal region. Operated on, May 20. Projectile removed from fracture of skull: a piece of the inner table which had been driven some 3 or 4 mm. into the brain was also removed, as were several splinters from the dura.

On Admission, June 26.—A triradiate scar in the left frontal region: depression over an area the size of a florin: pulsation and impulse on coughing marked. No motor symptoms. Headache: vertigo on bending forward.

Gradual cicatrization of wound.

Operation, Sept. 5.—Cartilaginous cranioplasty, with excision of the cicatrix. The gap was an irregular triangle, apex downwards, with a side of about one and a half inches.

The sequelæ were excellent. The skull was quite hard at the end of the month. He was discharged convalescent on Oct. 7. He still suffered from headache, but much less, and could bend forward without any trouble.

Case 2.—Soldat C. T. Wounded on Aug. 15, 1916. (No notes.)

On Admission, Sept. 3.—The patient presented a horseshoe scar, almost healed, on vertex. Trephine hole about $1\frac{1}{2}$ in. in diameter. No pulsation; very slight impulse on coughing: no headache or other symptoms; but any pressure on the gap causes acute pain.

Operation, Sept. 16.—Cranioplasty. The old semicircular flap was again raised. He developed a small hæmatoma, which was absorbed at the end of three weeks.

When discharged on Oct. 21, the skull was quite solid and he could stand considerable pressure on the grafts.

Case 3.—Soldat A. G. Patient was wounded on Aug. 2, 1916. (No notes.) Admitted to hospital on Sept. 3.

On Admission.—There was a large depression in right parietal area; the wound was nearly healed. Marked pulsation, and impulse. Headache; giddiness; insomnia. Slight weakness in left hand.

Operation, Oct. 4.—Cranioplasty. A crucial incision was made The fibrous tissue covering the dura was scraped off. The hole measured about 2 in. by 2¼ in. A large hæmatoma formed and had to be evacuated.

Nearly a month after operation there was still some pulsation in the centre, but by Nov. 25 the grafts were solid, and all impulse on coughing had gone. His hand was quite strong. He still suffered from headache, giddiness, and insomnia as much as before the operation.

Case 4.—Soldat L. G. This patient was wounded on Aug. 18, 1916, and admitted on Sept. 3. (No notes.)

On Admission.—Patient presented a granulating wound at vertex. There was visible pulsation; impulse on coughing; headache; and vertigo on bending forward.

Operation, Oct. 11.—Cranioplasty (Dr. J. A. Small). A crucial incision was made; the fibrous tissue covering the dura was curetted away; a silkworm-gut drain was employed. The defect was about 1¼ in. in diameter.

In spite of the drain, a small hæmatoma formed. By Oct. 19, however, there was no pulsation in the head, and at the end of the month the graft was quite solid. When discharged convalescent on Nov. 11, the headache and vertigo were much less.

Case 5.—Soldat J. P. Was wounded Aug. 2, 1916, and admitted Sept. 2. The notes only say "Trephined at Front—loss of brain matter—vision of right eye diminished."

Fig. 16.—*Case* 5. Before operation.

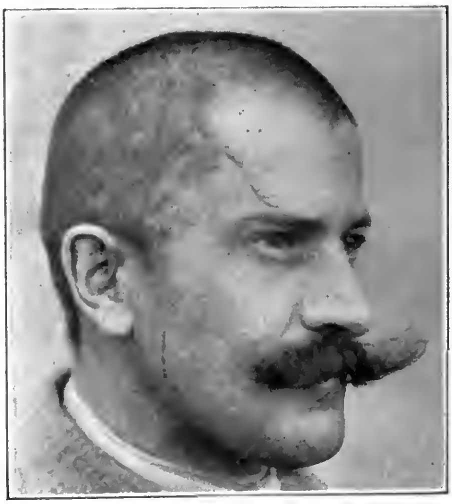

Fig. 17.—*Case* 5. After operation.

On Admission.—There appeared a depressed granulating wound above the right outer canthus. The depression was triangular, with sides about 1½ in. long. Visible pulsation, with impulse on coughing. Headache and vertigo.

Operation, Oct. 18.—Cranioplasty. The scar was excised. During the operation the dura was accidentally opened ; it was closed. Gap about 2 in. by 1 in. ; drainage.

Perfectly satisfactory healing of the wound followed, and consolidation of the graft: Patient can now (Nov. 25) bend forward with hardly any vertigo, and has had no headache for some days. The vision is clearing up. (*Figs.* 16, 17.)

Case 6.—Soldat E. B. This man received his wound on Aug. 21, 1916, and was admitted Sept. 3. The notes say : " Enlargement of scalp wound ; depressed fracture of skull ; fragment removed ; dura intact."

On Admission.—There was a small depressed wound about 1 in. above and behind the right ear, with visible pulsation, pain on pressure, and headache.

Operation, Oct. 23.—Cranioplasty. A round hole about 1 in. in diameter was found.

The wound was perfectly healed on Nov. 25, and the skull quite solid. He had much less headache, and listened to an opera with pleasure.

Case 7.—Soldat F. G. This man was wounded on Aug 1, 1916, and the notes say : " Furrow in right frontal region ; cerebral irritation ; internal strabismus. Operation on Aug. 3 : Removal of three splinters of skull from scalp ; gutter fracture found ; trephined ; incision of dura ; considerable subdural infection. Sustained improvement."

Fig. 18.—*Case* 7. Before operation.

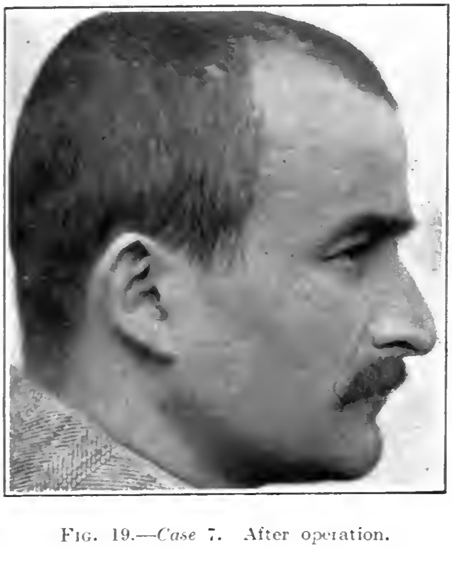

Fig. 19.—*Case* 7. After operation.

On Admission.—A granulating wound about $2\frac{1}{2}$ in. by 1 in. above and external to right eye ; visible pulsation, with impulse on coughing. On Sept. 4, much better ; up ; cannot bend forward ; and sleeps badly.

Operation, Oct. 28.—Cranioplasty. Excision of the scar ; irregular oval gap about $1\frac{3}{4}$ in. by 1 in.

Patient had a very slight attack of epilepsy on the next day. The wound was perfectly healed by Nov. 25, and the grafts are solid. He sleeps well, has no headache, and can touch his toes with very little discomfort. (*Figs.* 18, 19.)

SUMMARY.

It appears that in six out of seven cases we have improvement, and in most considerable improvement, of the symptoms complained of. Why *Case* 3 remains in his former state it is hard to say; if his condition gets any worse it will probably be necessary to remove the graft. In *Cases* 1, 5, and 7 the cosmetic result alone was worth the trouble. Except where noted to the contrary, the technique employed was that described. We attribute the hæmatoma formation in *Case* 2 to the use of a horseshoe flap, in *Cases* 3 and 4 to our error in scraping the fibrous tissue off the dura; we have modified our technique accordingly.

To sum up: While no one would maintain that every case of craniotomy should undergo a reparative operation, a very large percentage of such cases show symptoms which can be cured by cranioplasty. While many methods have been suggested, Morestin's cranioplasty by means of cartilaginous grafts is one of the easiest to perform; it can be undertaken at a comparatively early date; it gives a very high percentage of good results; the time of waiting for these results is short, and the operation is no more dangerous to the patient than is a radical cure of inguinal hernia.

No originality is claimed for this paper, which merely sets forth the work of others; but should it do anything to popularize this most useful operation among British surgeons, the writer will be amply rewarded.

The writer's best thanks are due to M. Villandre, not only for introducing the operation to his notice, but also for much valuable help in the description of the technique, which (as here described) is almost as much due to M. Villandre as to the original author.

Figs. 13 and 15 are the work of Miss D. Stronge, senior V.A.D. member of the hospital nursing staff. The photographs were taken by M. Oulmann, of Lyon.

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SEPTIC PERITONITIS: TREATMENT BY CÆCOSTOMY.

BY ARTHUR J. NYULASY, PERTH, AUSTRALIA.

AFTER operation on a septic focus within the abdomen, or after the preliminary pain and shock of an abdominal catastrophe, or as the result of hæmatogenous infection of the peritoneum, the collection of symptoms known as 'septic peritonitis' may appear. In the fully developed clinical picture there are two constants, viz. (1) Intestinal paralysis, and (2) Toxæmia. We also have to distinguish two more or less distinct pathological types, namely (1) With extensive inflammation of the peritoneum and little or no free fluid in the abdomen, and (2) With much free fluid but little inflammation.

The Two Clinical Constants.—

Intestinal Paralysis.—There is cessation of the passage of gas and fæces, and bowel sounds are negative to the stethoscope, i.e., there is acute intestinal stasis.

Toxæmia.—This is indicated by rapid progressive general deterioration, the pulse and respiration quickly reaching a high grade of frequency, the blood-pressure falling greatly, restlessness and thirst becoming marked, the patient feeling weak, showing a 'dirty' pallor, and looking ill, worn, and anxious, and dying in a day or two with sunken eyes, pinched nose, livid lips, and cold, clammy, tremulous extremities; the mind being clear, or delirium or euphoria being present before the end.

Qualitatively, intestinal paralysis and toxæmia are the two clinical constants. Such symptoms as distention, vomiting, fever, and pain may or may not be prominent features. Thus, while distention is often marked, there are cases in which it is absent, the abdomen being perhaps actually scaphoid. Vomiting is frequently a striking symptom, but in some of the worst cases it may be absent. It is usually of the regurgitant type, and in rare instances becomes definitely fæcal. The vomitus often consists of dirty-looking ill-smelling fluid, with solid dark flecks distributed through it ('beef-tea vomit'). While the bowels are in most cases obstinately confined, there are instances in which actual diarrhœa is present. Whether this is due to irritation or to an overflow is not decided, but experiments on animals suggest that it is toxæmic. The temperature is a variable sign, but is likely to be subnormal with the marked prostration of the later stages of septic peritonitis. Pain and tenderness may be pronounced or very slight, being more notable in cases with extensive inflammation of the peritoneum. Pain in the diaphragmatic region is in my experience a bad sign. Tenderness is best elicited by what I call the 'staccato touch,' the abdomen being struck lightly and sharply with the tip of the finger. This may bring out tenderness as a sort of wave over the whole abdomen, while, if there is much free fluid in the abdomen, the

sound of percussed fluid may be distinctly heard ('staccato sign'). Furthermore, the staccato touch may bring on regurgitant vomiting when it has momentarily ceased. From what has been stated it will be seen that the only absolutely constant feature of septic peritonitis is the progressive general deterioration.

Quantitatively, intestinal paralysis and toxæmia vary directly the one as the other, this depending on the fact that, as the result of acute stasis, a virulent toxin is formed in the paralyzed intestines, and the more complete the paralysis the greater the amount of toxin produced. This toxin is very depressing to the circulation, as evidenced by the low tension and rapidity of the pulse, the marked prostration, the pallor, the tendency to lividity of the lips and ears, and the cold clammy extremities.

Much evidence might be advanced to support the view that the intestinal paralysis leads to the formation in the bowel of a virulent toxin. Thus, in dogs in which acute stasis is artificially produced in a loop of duodenum, a toxin may be recovered from the loop, the injection of the fluid containing the toxin into the vein of a healthy dog causing toxæmic symptoms practically identical with those in the ileus dog (Stone, Bernheim, and Whipple). In either case the clinical picture does not materially differ from that of human septic peritonitis. As bearing on the value of intestinal drainage in septic peritonitis, the life of the ileus dog may be prolonged by drainage of the loop.

The Two Pathological Variables.—The analysis of a large series of autopsies of cases dying with the clinical features of what is usually signed up as 'septic peritonitis' reveals two fairly distinct pathological types: (1) Where there is extensive obvious inflammation of the peritoneum, and little or no fluid free in the abdomen; and (2) The type with much free fluid, but comparatively little inflammation. Although, in conformity with custom, 'septic peritonitis' is here employed to refer to either, it is clear that the expression can only be regarded as clinical, and not as the name of a definite pathological entity, adequate in itself to account for death.

In reference to these two great pathological types, we find that death in septic peritonitis is due neither to the one variable nor the other. A practically universal inflammation of the peritoneum may not in itself very seriously disturb the patient, as is shown in a paper on "Acute General Hæmorrhagic Peritonitis" which I contributed to the *British Medical Journal*, July 8, 1916; and as to toxic free fluid, it is only when this is under high tension, and is inadequately combated by the protective capacities of the peritoneum, that it becomes absorbed with sufficient rapidity to produce symptoms of its own, which, where there is pus, often appear to be those of euphoria.

The main rôle of the pathological variables is to produce intestinal paralysis. In the one type direct inflammation of the intestinal peritoneum is responsible: in the other, the free toxic fluid inhibits peristalsis by acting on the intestinal nerves.

Diagnosis.—In twelve to twenty-four hours after operation on a septic focus within the abdomen, when the effects of shock and anæsthesia are usually passing off, the patient, instead of beginning to improve, may rapidly and progressively go down hill. Thus, he may look unduly distressed, the colour

may not be good, perhaps assuming a 'dirty' pallor, with a suspicion of some darkening of the lips; there may be drying of the tongue and great thirst, together with restlessness, anxiety, and complaint of weakness and abdominal pain; while vomiting, instead of diminishing, is becoming more urgent, and perhaps foul and regurgitant. The pulse, instead of being 100 or less, is 120 or more, and its tension is not good, while the respirations are 28, 29, or more. The abdomen may be distended, and show little movement, and neither gas nor fæces may be passing, although in some cases there is actual diarrhœa.

With the suspicion of a commencing septic peritonitis, every effort should be made to get the bowels to act freely, as by calomel, Epsom salts, and enemata, and by pituitrin or eserine. Also, a system of hourly records of the pulse, respiration, and temperature should be at once begun. The records are placed in parallel columns, and carefully studied. The temperature may be subnormal in the later stages, while a sudden big drop to well below the normal may indicate perforation, say of inflamed bowel. If over a period of a few hours the records show that the pulse and respiration rates are rapidly and progressively increasing, and that the pulse tension is falling, while the general condition is steadily deteriorating, the paralytic ileus of septic peritonitis may be definitely diagnosed.

By this time the pulse is probably 130 to 140 and of very low tension, the respirations 35 to 40 and decidedly shallow, the face shows a 'dirty' pallor, the lips and ears are perhaps livid, the eyes sunken, the nose pinched, while the expression is drawn, weary, and anxious, and the hands cold, clammy, and tremulous. With these signs of deterioration established, though vomiting or even distention is absent, and though actual diarrhœa is present instead of constipation, the patient will inevitably die unless intestinal drainage be promptly instituted.

I am satisfied that in the majority of post-operative cases with rapidly increasing pulse and respiration rates, but without any notable fall of pulse tension, we are dealing merely with a *paresis* of the intestines, and that stasis is as yet far from complete. Probably even with this incomplete stasis intestinal toxin is manufactured, but not in quantity sufficient to cause any marked fall of blood-pressure, although quite adequate to greatly quicken the pulse and respiration. Whether this explanation is strictly accurate or not, we have the practical fact that in many such cases free purgation soon reduces the pulse and respiration, and that the patient proceeds to recovery. My conviction is that in most of these cases the patient would, in the absence of free purgation, soon show the fall of pulse tension and the other signs which announce the presence of definite paralytic ileus.

Treatment.—In the *Australian Medical Gazette*, May 24, 1913, I described three cases of post-operative septic peritonitis apparently saved from death by intestinal drainage, the first case being dealt with on May 31, 1912. I subsequently reported three additional cases, and finally embodied these six consecutively successful cases in an article in the *Lancet* of October 9, 1915. In April of the following year (1916), papers on intestinal drainage were contributed by Mr. Sampson Handley and by Mr. Victor Bonney to the *British Medical Journal*, Mr. Handley giving "general peritonitis with obstruction" as

the broad indication for intestinal drainage, and Mr. Bonney relying largely on "fæcal and intestinal vomiting."

Mr. Handley appears to regard general peritonitis as an extensive obvious inflammation of the intestinal peritoneum, and draws a striking clinical picture of such a case where obstruction is present. He says: "Cessation of the passage of gas and fæces, and persistent foul vomit, indicate that complete obstruction has supervened . . . The abdomen is uniformly and tightly distended like a drum. The pulse becomes running, the extremities cold . . . and the patient, only within a few hours of the end, realizes . . . that he is in the inexorable grasp of death." In this advanced stage Mr. Handley believes that "the surgeon's chance has gone."

As already indicated, cases presenting a clinical picture practically identical with that so vividly painted by Mr. Handley, may show but little evidence of inflammation of the peritoneum, the only really obvious pathology being abundant fluid free in the abdomen. As to the stage in the evolution of septic peritonitis at which intestinal drainage may be successfully employed, my experience is, that, even with such a clinical picture as Mr. Handley describes, the surgeon need not despair. The following case illustrates this view.

Paralytic Ileus; Fæcal Vomiting; Cæcostomy.—Female, age 24, admitted to Perth Hospital. At operation (May 5, 1915), abdomen found full of dark blood and clots from rupture of ectopic gestation three weeks earlier. The offending tube was removed; but on account of the grave condition of the patient, the abdomen was closed while the washings were still very dark. The patient deteriorated, and within thirty-six hours obstruction was absolute, while the vomiting was fæcal and profuse, 20 ounces being ejected in one bout at 8 a.m., and then continuing till noon, by which time 18 ounces more had been ejected. The fluid had a strikingly fæcal odour, and in every way suggested the contents of the lower ileum. The pulse was now 160, respirations 40, and temperature 96·4°; the abdomen was enormously distended and immobile, the extremities were cold, clammy, and tremulous, the lips dark, eyes sunken, and the face was intensely pale. On opening the abdomen over the cæcum much dark bloody fluid welled out on to the bed; that remaining within the abdomen was only roughly mopped out. A rubber tube was purse-strung into the cæcum. Within a few hours vomiting had ceased, and in less than twenty hours the abdomen was flat, and the patient taking milk.

I find it difficult to agree with Mr. Victor Bonney that "all cases of paralytic intestinal obstruction . . . when advanced to the stage of fæcal, or short of fæcal, intestinal vomiting, should be subjected to jejunostomy." The case of fæcal vomiting just described goes, I think, to justify my attitude, since simple cæcostomy sufficed to rescue the patient.

Mr. Bonney refers to instances in which, after failure of cæcostomy alone, jejunostomy has relieved. In this connection it is important to carefully exclude possible errors of technique in the cæcostomy. Thus, I recall one case in the Perth Hospital in which, a few hours after cæcostomy, the patient became so excited and obstreperous that she had to be strapped in bed. I found the rubber drain-tube was perished, and had thus been completely occluded in tying the purse-string used to fix it in the cæcum. On putting matters right the symptoms rapidly improved, and a couple of days later she was enjoying the newspaper. In this case the patient had been in a very

grave condition—enormous distention, continuous foul regurgitant vomiting, pulse 140, respirations 40, temperature 96°, and cold, clammy extremities.

Fæcal vomiting is in my experience an excessively rare complication of septic peritonitis, although Mr. Bonney describes it as occurring in no less than five of his six cases of intestinal drainage. Although, when indubitably present, the indication for intestinal drainage is positive, still in some cases of septic peritonitis in which vomiting is practically absent, drainage of the bowel may be the one measure likely to avert death. The only true index of the urgent need for intestinal drainage is the rapidly progressive general deterioration, as indicated by the high and increasing pulse and respiration rates, the fall of blood-pressure, the drawn, weary expression, the prostration, the dirty pallor, the lividity of the lips, and the cold, clammy, tremulous hands.

Cæcostomy.—The rational treatment of the intestinal toxæmia of septic peritonitis is the removal of unabsorbed intestinal toxin and the prevention of its further production. Both these ends may be secured by intestinal drainage—provided that the peritoneal cavity is not charged with excessive poison, that the focal factor is eliminated, and that such a large quantity of toxin has not been absorbed already as to render any form of treatment futile.

The case of fæcal vomiting already described, suggests that in septic peritonitis cæcostomy alone will adequately drain the paralyzed intestines of the toxin which is rapidly destroying life, and others of my cases point to the same conclusion. I do not assert positively that cæcostomy is the only form of intestinal drainage needed in septic peritonitis, but I believe that the exceptions to this rule will be but few. The primary objective of intestinal drainage is the removal of toxin from the bowels, and if cæcostomy did not soon relieve the symptoms, drainage of the intestine higher up should be instituted in addition. Bearing in mind the possibility of such a step being demanded subsequent to cæcostomy, the hourly records should still be continued in all cases, and the patient still be watched with the most scrupulous care for at least the next twenty-four hours, saline infusion, the electric-light bath, and other measures being persevered in. If after some hours—and we cannot be more definite—improvement has not clearly set in or, worse still, there is evidence of continued deterioration, the abdomen should at once be opened under local anæsthesia a little above the umbilicus, a rubber tube purse-strung into the most distended loop of small intestine, and the abdomen rapidly closed with silkworm gut. To have carried out by Mr. Handley's very ingenious device (anastomosis of the jejunum with the transverse colon) such extra intestinal drainage coincidently with cæcostomy would have demanded exceptional daring in my case of fæcal vomiting.

In my series of cases, as soon as the opening into the cæcum was made, the fæces usually came out under high pressure, in one instance rising up in a stream over eight inches high. If the cæcum had contained this fluid before it had been opened, we may reasonably assume that the fluid would have been forced along the colon to the anus. Since this had not happened, it seems likely that these fæces had not yet reached the cæcum, but were held back in the ileum, and that the opening of the cæcum relieved the obstruction. Perhaps, then, the efficacy of cæcostomy may depend on a possible power to

relax ileo-cæcal spasm, and thereby release virulent fæces pent up in the small intestines.

Technique.—Through an oblique abdominal incision a fold of the cæcum is isolated by a pair of semicircular bowel forceps, and the parts are packed off with gauze pads. A catgut purse-string taking up only the outer coats of the cæcum is now placed, the bowel incised, and any fæces mopped away. A piece of $\frac{1}{3}$-in. rubber tubing is passed into the bowel, the raw edges are turned in, and the purse-string is tied. The rubber tubing is then carried on to a bottle fixed to the bedstead, and the bowel clamp removed. A second purse-string attaches the cæcum to the peritoneum, the ends closing the internal oblique, while a couple of silkworm-gut sutures unites the skin and aponeurosis. The bowel tube becomes loose in about four days.

If, after several weeks, the cæcal fistula does not close, it may be dealt with by the simple method described by Dr. Frank Nyulasy, of Melbourne, in the *Australian Medical Journal*, and subsequently by Greig Smith in the later edition of his *Abdominal Surgery*. Semilunar incisions surround the fistula, and extend down to, but not through, the parietal peritoneum, which is then freely undermined to loosen it; the fistulous tract is removed, and the opening in the bowel sutured, the remainder of the wound being closed in the usual manner. Frank Nyulasy did his first case under cocaine anæsthesia. A fistula into the small intestine may be similarly closed three to four days after being made.

CONCLUSIONS.

In treating septic peritonitis, it is to be clearly borne in mind that a virulent toxin in the paralyzed bowels is rapidly killing the patient, and that there is only one certain method of removing this toxin, namely, by opening the intestines and draining them—always provided that before doing so the septic focus is eliminated, the abdominal cavity cleansed of excessive poison by swabbing, douching, and efficient drainage of septic necrotic areas, and further, that purgatives, saline injections, and eserine or similar drugs have been given a fair trial. As to the route, my own preference is for cæcostomy, a faith justified, I venture to believe, by my personal experience. If cæcostomy does not soon relieve, drainage of the bowel higher up should be instituted.

In military surgery I would, in a severe wound of the intestine, recommend either (1) Immediate excision, repair by anastomosis, and cæcostomy later if the patient deteriorated from paralytic ileus; or (2) Direct drainage of the injured bowel by Paul or rubber tubes for three to four days, and then repair by anastomosis.

ULCERATION OF THE COLON IN THE NEIGHBOURHOOD OF GUNSHOT WOUNDS.

By Captain JOHN SHAW DUNN, R.A.M.C. (T.C.),

and Captain HAMILTON DRUMMOND, R.A.M.C. (T.)

(*A Report to the Medical Research Committee.*)

It is, we believe, common experience, that wounds of the colon caused by missiles which perforate the viscus, differ little in character from the lesions so produced in the small intestine. If they are seen early, and closed by appropriate methods, they may be expected to heal readily and give satisfactory results if unassociated with other serious complications. The lesions of the colon which we propose to describe in this paper differ markedly from such direct wounds, not only in respect of their causation, but also as regards immediate and ultimate prognosis. We have observed that where a missile has passed near to a fixed portion of the colon, without actually touching its wall, it may give rise to an appearance of extensive ulceration of the colic mucous membrane. This form of ulceration is very liable to extend deeply into the intestinal wall, and to be followed by perforation and peritonitis or retroperitoneal cellulitis. The condition is therefore, of itself, a very grave form of injury, and may frequently prove fatal apart from the effects of other lesions which may accompany it. There is little doubt, however, that ulceration of this type is sometimes present in cases which ultimately recover. We have had opportunities of observing it only at very early dates after wounding, and only in cases which proved fatal: but it has not always been the direct cause of death. Further, we have been informed by General Sir Anthony Bowlby that fæcal fistula is a not infrequent late development in relation to wounds of the loin which are known not to have penetrated the intestine. It seems very probable that the condition we describe will afford an adequate explanation of an occurrence of this kind.

Case 1.—S., age 30, was wounded at 2 a.m. on June 30, 1916, and admitted to hospital twelve hours later. When seen, he was suffering severely from shock; there was general rigidity of the abdominal wall, and marked tenderness over the lower half of the abdomen. A small round wound of entry was found in the left loin, just above the iliac crest, and four inches behind the anterior spine. The exit wound, also on the left side, was at a point half an inch above the middle of Poupart's ligament.

At operation, twenty hours after wounding, the descending colon was exposed through an oblique incision in the left loin, parallel to the track of the missile. No perforating wound was observed on the colon, but two areas of hæmorrhage were present on its wall, one at the level of the entry wound, and the other an inch and a half lower down. The lower of these bruises, which extended circularly round the bowel, was much blackened, and there appeared to be commencing gangrene,

involving the peritoneal coat. This damaged area was covered in by Lembert sutures, and the wound was drained. The general condition of the patient was very bad, and death occurred shortly after operation.

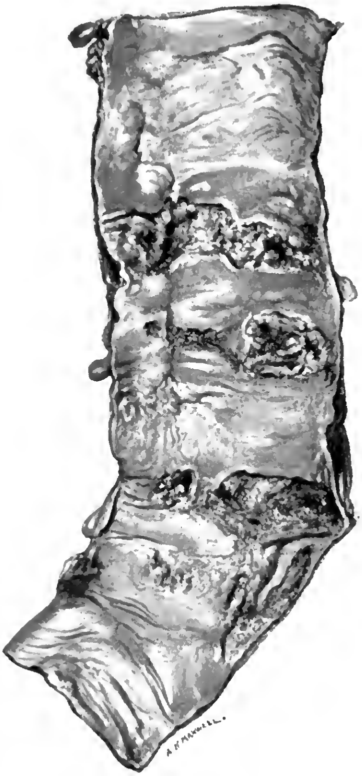


FIG. 20.—Ulcerated portion of descending colon in *Case* 1. The ulcers tend to encircle the wall of the viscus. Their bases are formed by submucous tissue, containing much blood.

The outward appearance of the descending colon was as seen at operation, but a third area of bruising was noted two inches below the lower of those previously mentioned. The track of the missile was mainly extraperitoneal, and not directly against the colon; there was certainly no gross laceration of the outer wall of the viscus. On opening this portion of the colon, three areas of ulceration were found on the mucous membrane, corresponding in position to the zones of hæmorrhage seen externally. The ulcers, which were fairly extensive (*Fig.* 20), tended to be annular in shape; but only the uppermost of them encircled the lumen completely. They penetrated into the submucous layer, but not through it. The bases of the ulcers were black with altered blood, and appeared to be gangrenous. By careful dissection, the mucous and submucous coats, with the ulcers, could be stripped from the muscular layer. The separation was effected with particular ease in the regions of the ulcers, where slight hæmorrhage had taken place between the layers. Many of the minute blood-vessels perforating from the muscular to the submucous coat had evidently been torn across in these areas. Underneath each ulcer there was some damage of the circular layer of muscular fibres, but this was of slight extent compared with the lesions in the mucous membrane. It consisted of short linear tears, running across the muscular fibres (*Fig.* 21): the lesions occurred in the sacculi, between the longitudinal muscular bands.

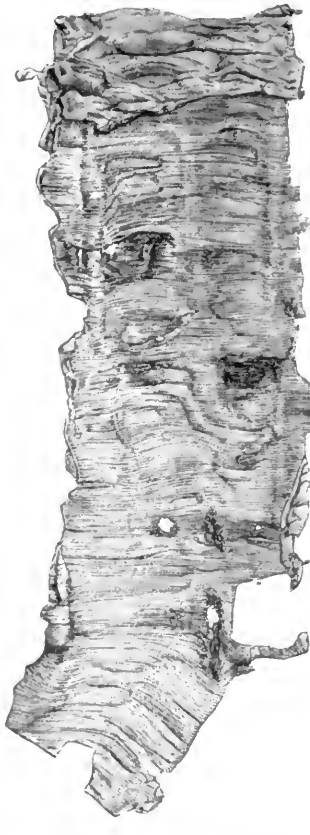


FIG. 21.—Musculature of wall of descending colon in *Case* 1, underlying the ulcerated areas. Some laceration of the circular fibres is visible at places which coincide with the points of deepest ulceration. The longitudinal bands of muscle are intact in this case. Note indication of hæmorrhage around the lacerations.

Case 2.—D. was wounded by a rifle bullet at 11.30 p.m. on Sept. 9, 1916, and was admitted to hospital five hours later, in a condition of shock. A small round wound of entry was found in the middle line of the back, at the level of the fourth lumbar spine. The exit wound, which was much larger, measuring one and a half inches across, was in the left

mid-axillary line, at the level of the tenth rib. A loop of the transverse colon, with a portion of great omentum, was prolapsed through the latter wound.

At operation, six hours after wounding, the condition of the abdomen was examined through a mesial incision. There was no visible lesion of the transverse colon, either inside the abdomen or on the extruded portion, but a circular band of hæmorrhage, associated with an appearance of early gangrene, was observed on the wall of the descending colon just below the splenic flexure. This damaged portion of descending colon was drawn out posteriorly through a small left flank incision. Death occurred twenty-six hours after operation.

There was slight early general peritonitis. The bullet track was found to pass forwards and to the left through the deep muscles of the back, behind the descending colon, and through the posterior edge of the spleen. Thence it passed through the diaphragm at its costal attachments, and through the ninth and tenth ribs, portions of which, one to one and a half inches in length, were missing. There was no ulceration in the portion of transverse colon which had prolapsed. On the other hand, at the level of the annular zone of bleeding in the muscular coat, there was a patch of ulceration on the outer and anterior aspect of the bowel. The ulcer was of hour-glass shape, its two segments lying over sacculi, and the isthmus over the external longitudinal band. The base of the ulcer, which was formed by gangrenous submucous tissue, was black with hæmorrhage. On dissecting off the mucous and submucous coats, two irregular lacerations were found in the circular muscular fibres which underlay the broad parts of the ulcer. The penetrating vessels to the mucous coat had been torn in these areas. The lesions in the muscular coat were of small extent compared with those in the mucosa.

Case 3.—M., age 21, died seven hours after being wounded by a rifle bullet which traversed the abdomen from right to left.

It was found that the track passed through retroperitoneal tissue, below the lower pole of the right kidney, and into the body of the third lumbar vertebra, which was comminuted. The missile had thence passed forwards through the left side of the peritoneal cavity, wounding directly the transverse colon and a loop of jejunum, and had made its exit through the anterior abdominal wall. There was no direct wound of the descending colon, but there was much bleeding under its peritoneal coat, and in the retroperitoneal tissue. The hæmorrhage in the wall of the colon was irregularly distributed along four inches of the bowel. This portion of descending colon, when laid open, presented several large areas of ulceration of the mucous membrane. The ulcers were irregular in shape, and the depth to which they penetrated varied in different parts. They were deepest, reaching the muscular coat, in the sacculi between longitudinal bands. The mucous membrane and submucous coat were dissected off from the muscular layer. It was then seen that beneath the areas of hæmorrhagic ulceration there was slight bleeding on the surface of the circular muscular coat. The separation of the layers could be effected with great readiness in these areas, and many of the small blood-vessels perforating from muscularis to submucosa had evidently been torn across. Several lacerations of fibres were found in the circular muscular coat under the deepest parts of the ulcers. The lacerations extended across the fibres, in the long axis of the intestine, and they were situated in the unsupported sacculi. No portion of muscular tissue had been actually torn away. Microscopic examination of two of the ulcerated areas showed tearing of circular fibres, and hæmorrhage between the torn ends.

Case 4.—W., age 21, had received multiple grenade wounds at 4 p.m. on Oct. 27, 1916, and he was admitted to hospital at 7 p.m. on the same day. When seen on admission, he was suffering severely from shock, the pulse being 140 per minute. The abdomen was very rigid and retracted, and showed scarcely any respiratory movement. Two small entry wounds were found on the anterior wall of the abdomen: one of these was two inches above the left anterior superior iliac spine, and the other about an inch to the left of the first, at a slightly higher level: a tag of omentum projected from the latter wound. There were other severe wounds on the limbs.

Laparotomy was performed in the middle line. A large perforating wound was

found in the pelvic colon, and another in the upper part of the jejunum. The latter wound necessitated resection, while that in the pelvic colon was brought out through a separate incision in the left flank, as a colostomy. The tracks of the two missiles were seen to pass into the posterior abdominal wall, one on either side of the descending colon. The wall of that viscus showed some hæmorrhage opposite the level of these wounds, but there was no perforation, and no evidence of direct damage. Death occurred five hours after the operation.

It was confirmed that there had been no direct injury of the descending colon by either missile: the missiles, two portions of rifle-grenade, were found embedded in the muscles of the posterior abdominal wall. The descending colon, when slit open, showed an area of ulceration an inch in diameter, towards its anterior aspect, at the level of the hæmorrhage seen externally. The ulcer was of irregular outline, and its base was infiltrated by blackened blood. This ulcer, when examined microscopically, was seen to be associated with tearing of the circular coat of muscular fibres. Much hæmorrhage was present in the submucous tissue, and in the fissures in the muscular layers.

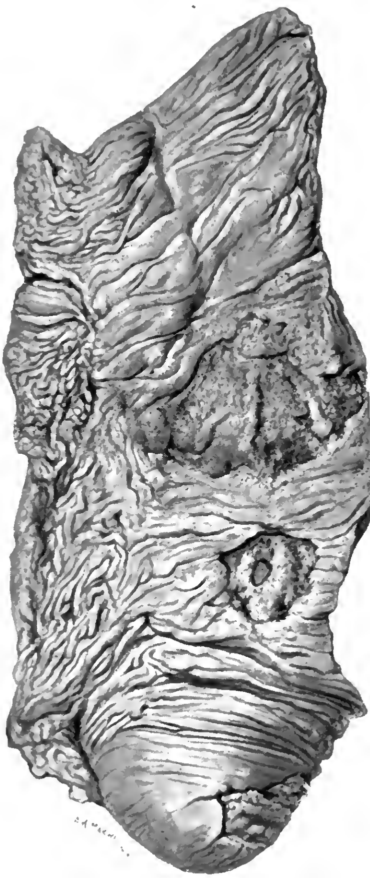


FIG. 22.—Mucous surface of caput cæcum and part of ascending colon in *Case* 5. There are three fairly extensive ulcers on the posterior wall, one being in the caput. The base of each ulcer is formed by the submucous layer, and is much infiltrated with blood.

Case 5.—G. was wounded by a rifle bullet at 11.30 p.m. on June 17, 1916, and was admitted to hospital six hours later, much collapsed. A small round entry wound was present in the left buttock, and the exit wound, which was larger and irregular, was in the right mid-axillary line at the level of the costal margin.

Laparotomy was performed shortly after admission. There was no evidence of injury of the abdominal viscera, except some hæmorrhage on the wall of the cæcum and behind the peritoneum of the right flank. Some blood-stained urine was passed a few hours later. Death occurred twenty-one hours after wounding.

It was found that the wound-track passed from the left buttock through the sacro-sciatic notch and the upper part of the sacrum, through the belly of the right psoas muscle, and thence between the right kidney and the ascending colon. Neither of the latter viscera had been directly touched; a layer of retro-peritoneal fat a quarter of an inch in thickness intervened between the track and the colon wall. There was cellulitis and gangrene around the wound-track in the retroperitoneal tissue, and films and cultures made later from this material showed abundant gas-forming, anaerobic bacilli. The capsule of the right kidney was intact, but two subcapsular lacerations were present in the cortex on the anterior aspect of the lower pole. The ascending colon exhibited externally only some hæmorrhage on its inner side. When this portion of bowel was opened, two large areas of ulceration were observed on the posterior wall, while a third was seen in the caput cæcum (*Fig.* 22). The two uppermost ulcers lay almost directly over the bullet track. Each ulcer

penetrated deeply into the submucous coat, but not quite through it: the bases were necrotic, and dark with hæmorrhage. The mucosa and submucosa were then dissected off from the muscular layers. By this means it was shown (*Fig.* 23) that underneath the middle and uppermost ulcers the posterior longitudinal band of muscle had been sharply torn across. The torn ends were widely retracted, and the circular fibres, though not lacerated, were drawn apart with them, so as to leave a complete wide gap in the muscular layers. Each of these lesions was associated with some hæmorrhage, and the exposed retroperitoneal tissue was foul and gangrenous. A like muscular lesion was also observed in the outer longitudinal band, opposite the level of the upper ulcer, but it was unaccompanied by hæmorrhage or by ulceration of the mucosa. In relation to the ulcer in the caput cæcum, there was only slight tearing of the circular fibres, with some hæmorrhage.

Case 6.—B. was struck by a piece of shell in the region of the right buttock at 5 a.m. on Sept. 11, 1916. He was admitted to hospital in a condition of extreme collapse, and died thirteen hours after receipt of injury.

An entry wound, the size of a half-crown, was present on the right buttock over the great sacro-sciatic notch: the exit wound, much larger, centred round the site of the right sacro-iliac joint. The greater part of the right side of the sacrum, and the posterior end of the iliac blade, had been carried away by the missile. The perirectal adipose tissue, which was exposed in the wound, was not actually lacerated, but exhibited much diffuse hæmorrhage over an area two inches in diameter. The appearance of the tissue indicated commencing gangrene. The rectum was removed, and opened from the front. A large and deep ulcer was found on its posterior wall corresponding in site to the hæmorrhage seen posteriorly. The lesion measured two and a half inches across and one and three-quarter inches in length, and had a hæmorrhagic, gangrenous base composed of perirectal adipose tissue (*Fig.* 24). Two areas of superficial ulceration, associated with hæmorrhage, were present on the rectal mucosa at a lower level. The appearance of the large lesion was very suggestive of the actual loss of a large portion of the muscular and mucous coats, but in view of the fact that the injury took place only thirteen hours earlier, it is apparent that the gap must be explained by the retraction of torn edges of tissue. The tear was evidently not produced by immediate contact of the missile, for behind it the layer of adipose tissue was three-eighths of an inch in thickness. The superior hæmorrhoidal artery was traced downwards through

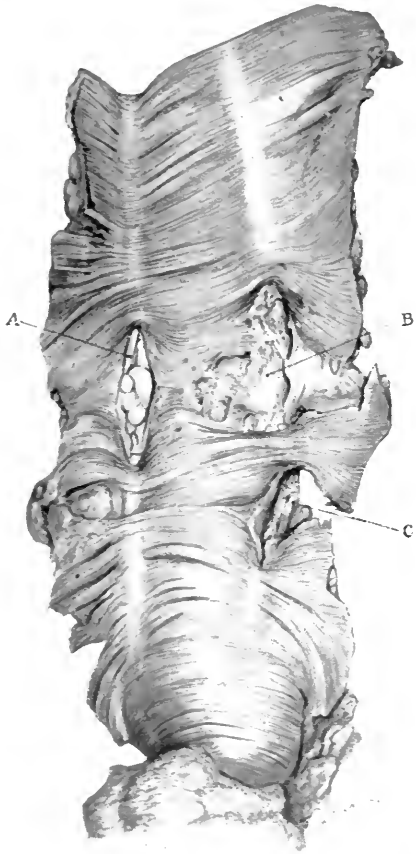


FIG. 23.—The muscular wall of the colon underlying the ulcers shown in *Fig.* 22. The posterior longitudinal band of muscle is torn across in two places (B and C), and the torn ends have retracted, drawing with them the fibres of the circular layer. It is seen that these lesions in the muscle correspond exactly in site with the two ulcers in the ascending colon. The tear in the outer longitudinal band, marked A, was unassociated with ulceration. The arrangement of the muscular lesions in this case affords good evidence that they were produced by indirect violence, as all of them were caused by one rifle bullet.

this tissue to its finer branches. The wall of the vessel showed some hæmorrhagic staining, but no actual rupture.

The feature which attracted attention in this group of six cases was the appearance of extensive ulceration of the intestinal mucous membrane, where the external aspect of the bowel had not given rise to suspicion that such a condition existed. These lesions were fully developed at remarkably early periods—from seven to twenty-six hours—after receipt of the causal injuries. In each case it could readily be ascertained that the ulceration had arisen in relation to the passage of a missile which did not perforate the viscus, or even come into direct contact with its wall.

Fig. 24.—Ulceration or laceration of wall of rectum in *Case* 6. This condition was observed fifteen hours after wounding by a piece of shell. The missile destroyed a great part of the sacrum, but did not actually lacerate the retroproctal adipose tissue. The superior hæmorrhoidal artery could be traced to its finer branches. The gap in the mucous and muscular coats had thus been produced by transmitted violence.

In explanation of the lesions, two main facts have been observed by dissection. First, there was always some laceration of the muscular coats, though this was usually very slight in extent compared with the lesion in the mucosa, and it was not associated with actual loss of muscular substance. In one instance (*Case* 5), the damage to the muscular layers had clearly been produced by a dragging effect transmitted through strands of fibrous tissue or blood-vessels: in this case there was also deep laceration in the cortex of the kidney, though the capsule was intact. In the other cases, the effects were most probably due to sudden impact on a gas-filled sac, resulting in bursting at weak points. The lacerations here occurred most commonly in the unsupported sacculi; evidence has previously been brought forward by one of us to show that in the normal sacculi there are specially weak points where the larger vessels perforate the muscular wall to reach the mucous membrane.[1] In referring to the damage to the muscular coats, it seems important to note that the lesions have been observed only in fixed portions of the colon, and never in the freer parts supplied with a mesocolon, or in the small intestine.

The other fact of interest was that many of the perforating vessels to the mucosa in the damaged areas were torn across at the points where they passed from the muscular into the submucous coats. This afforded an explanation

of the great extent of loss of mucous membrane where the injury of muscle was comparatively trivial: the patch of mucosa had really been killed by loss of blood-supply.

In all cases it was apparent that the damaged tissues were subjected to early infection from the lumen of the bowel, and readily became gangrenous: at later dates the loss of tissue from this cause would no doubt have been much greater.

From the point of view of treatment, it is evidently important to provide adequate drainage of wounds in the flanks in all cases where definite bruising is visible on the wall of the colon; this applies particularly to the fixed ascending and descending parts.

REFERENCE.

[1] Drummond, *Brit. Jour. Surg.*, 1917, iv, No. 15, 407.

THE EARLY TREATMENT OF GUNSHOT FRACTURES OF THE THIGH.

By Captain C. MAX PAGE, R.A.M.C. (S.R.),

and Captain A. B. LE MESURIER, R.A.M.C.

After two and a half years of war, surgical opinion as to the most satisfactory method of treating compound fractures of the femur is by no means unanimous. One school, following Lieutenant-Colonel Robert Jones,[1] maintains that the best results can be obtained in general by a 'fixed' long-axis pull with the limb in a position of extension. Another school, of which Major Hey Groves[2] is the champion, contends, as did the old surgeons, that true alinement cannot be obtained when the limb is extended at both knee and hip, and that the position of the double inclined plane is the correct one; moreover, continuous weight extension is favoured, as opposed to fixation in extension.

The procedure of plating gunshot fractures, at any stage, except as a very exceptional measure, has fallen into the disrepute the results justify.

In the course of our experience in this war we have treated fractures in accordance with both the above-mentioned principles. For the purposes of *transport*, there can be no question that the Thomas knee splint, or one of its modifications, is the best arrangement available. On account of its extreme value in this respect, and for its convenience in wound treatment, there has been a tendency to perpetuate its use in the classical form for the late treatment of unsuitable cases. From our observations we are firmly convinced that in fractures in the lower third of the femur, the commonly occurring flexion of the lower fragment is seldom, if ever, completely controlled by a straight Thomas knee splint. For these cases we have used the Thomas splint, but bent at the knee level, thus obtaining a skeleton inclined plane. By the use of this method our results have been much improved, as far as alinement is concerned.

We propose here to deal with the practical treatment of gunshot fractures of the thigh in the period during which wound treatment and proper apposition of the bone fragments are the chief problems. We also deal, as far as our experience permits us, with the measures which, adopted at this stage, assist the restoration of function.

Our conclusions are drawn from observations on 198 cases. Systematic notes on the forms furnished by the National Research Committee have been kept on the last consecutive 125 of these cases, and statements in this article are based on the latter group. Cases of gross injury to the knee or hip-joint have not been included in the series, nor those cases in which immediate amputation was undertaken for spreading gas gangrene.

We have throughout used splints and material of standard pattern, and such as are issued from the Army Medical Stores.

The following statistical statement gives a general outline of the cases dealt with :—

Total number of cases	125
Fracture in subtrochanteric area	26
,, upper third of femur	21
,, middle third	30
,, lower third	44
,, supracondylar area	7
,, both limbs	3
Cases not infected	10
,, of mild infection	16
,, medium infection	28
,, severe infection	71
Average period between injury and observation	78·8 hours
,, ,, of observation of cases ..	51·5 days
Average amount of shortening on transfer ..	0·378 inch
Number of amputations	4
Number of deaths	10

'*Concussion*' *Fractures.*—In this series, 13 cases showed fractures, on x ray examination, either oblique or of the 'flûte en bec' type, with little or no comminution at the seat of injury. In these cases the missile lodged, generally, near the bone, though in two instances it appeared to have no relation to the latter. Infection of the wound was present in all instances, and was classified as mild in 5, moderate in 5, and severe in 3. In no case did signs of severe bone infection ensue.

This type of fracture is presumably due to the local concussion action of a slow-travelling missile. In general, the prognosis for this class of fracture is better than in the cases in which the bone has been perforated and comminuted.

Our aim has been to keep every case under observation till any infective process has been reduced to a minimum, and till union has commenced in good line and without undue shortening.

The final functional results we have only been able to observe in a few cases, though we have received reports from home hospitals of the after-course of a fair number.

WOUND TREATMENT.

As might be expected, in the course of dealing with an extended series of cases, the method of wound treatment has varied with the ideas of the time. As the full discussion of this complicated subject is beyond the scope of this paper, we will merely state our views of it in dogmatic form, and attempt to define what we conclude to be the ideal procedure in these cases.

Primary Operative Procedure.—In all cases satisfactory drainage should be established once and for all at the earliest possible moment after the injury. Repeated anæsthetics and operations during the early period are to be deprecated in the treatment of these cases. The necessary procedure should therefore be effected at the casualty clearing station, where in any

case the patient is anæsthetized for cleaning up and the application of a splint. If practicable, the surface of the whole wound track should be excised; excision or incision of the skin wounds alone is a useless procedure. All fragments of bone lying loose should be removed; if left, they are a frequent source of persistent local infection: and there appears to be no doubt that so long as the periosteum is not unduly damaged, perfect union results, despite the loss of considerable amounts of compact bone. We prefer to pack the wounds so treated with dry sterile gauze. In the earlier cases of the series we employed tube drainage down to the bone from the posterior wound, but the limitation of infection seems to be better effected with the simple gauze pack. If the original wound or wounds do not furnish posterior drainage, a four-inch incision should be made on the postero-external aspect of the limb, and access gained to the seat of fracture along the line of cleavage between the outer hamstrings and the vastus externus: a part of the latter will have to be cut away in order to make the opening a free one.

Routine Dressing.—The primary gauze pack should be left undisturbed for two or three days, in the absence of signs of spreading infection; it should be removed and lightly renewed at intervals for a week or so; at the end of this period, in favourable cases, no further mechanism to keep the wound open will be necessary. A tube drain through the posterior hole down to the bone should be employed when there is evidence of continued osteitis and retention of discharge. In these latter cases a considerable saving in outside dressings may be frequently effected by passing the tube between two support slings and allowing the discharge to drip into a porringer. The outside dressings should be changed every twenty-four hours while acute infection is still active. During all processes the limb should be moved as little as possible, and it should never be necessary to roll the patient on his side for any purpose.

Spreading cellulitis of streptococcal origin, arising as it commonly does soon after the injury, is best left to take its own course, assuming that proper drainage has been established in the first place. Further incisions at this stage hinder rather than assist the patient's natural defence.

We have seen no case of *erysipelas* at this stage, though it occurred sporadically in four cases after sequestrectomies, and then pursued a usual course.

The *Bacillus aerogenes capsulatus* is present in many cases of severe infection, but it does not lead to progressive necrosis and toxæmia in those in which the wounds have been laid open in good time. If gas formation occurs in such an open wound, and no severe toxæmia is present, the case should be left quiet, and the wound will rapidly clean up. When spreading gangrene occurs, free incisions may suffice to arrest the process; if there are signs of severe toxæmia, amputation will be the only course. Local excision of the necrotic area in this class of case does not seem to be practicable so frequently as in lesions in the lower part of the leg.

SPLINTS.

The treatment of infective gunshot fractures may be roughly divided into three periods, in each of which the splint problem varies slightly. These are: (1) The period of early transport; (2) The period of acute infection; (3) The period of healing.

1. *The Period of Transport.*—The Thomas knee splint is the best available appliance. It is easily packed and handled, and is simply applied. It affords means of efficient self-contained extension, and allows of free access to all wounds. Moreover, it is sufficiently efficient even when the ring does not fit.

For those cases in which the presence of a wound about the hip-joint prevents the application of a Thomas splint, a Liston long outside splint, or some modification of it, is most suitable. It is not easily applied efficiently, on account of the difficulty in fixing it firmly to the pelvis, and it is not convenient for wound treatment.

2. *The Period of Acute Infection.*—The Thomas knee splint is suitable for all fractures occurring in the lower two-thirds of the bone. It secures the necessary immobilization under moderate extension, and affords free access to the wounds. For all fractures in the upper third, the Hodgen splint is well suited at this stage.

3. *The Period of Healing.*—This may be regarded as commencing in the second or third week. The chief object is to secure proper position of the bone fragments. In the lower third of the bone we use the Thomas splint in a modified form; the leg is pulled out to full or over length, and then, generally under anæsthesia, put up in flexion in the same splint bent at the knee level. Fractures in the middle third can readily be controlled in the classical form of the Thomas splint. For the upper third we use the Hodgen splint in general; in some cases, however, it is difficult to maintain sufficient flexion at the hip to secure good alinement, and other measures must be adopted.

Details of the Thomas Knee Splint.—The proper action of this splint depends on a close fit of the ring, so that the upper *point d'appui* shall be the ischial tuberosity. For average cases, rings with an internal circumference of 23 to 26 inches secure this condition. The impositions of active service have as yet made it impossible to secure a fit in the majority of cases, and we have commonly used splints with an inside diameter of 27 inches or more: such splints take purchase in the main on the bones of the ischio-sacral angle, and though not so comfortable as the correct pattern, they allow of full extension being made. To all these splints we add a prop of aluminium. This prop (see *Fig.* 25) should be wide based, and placed at least six inches up from the foot level, so that there is no risk of its slipping over the edge of a stretcher. The malleable nature of the prop allows of its being adapted to the slope of the stretcher when necessary; if made of iron, an adjustment for this purpose should be provided. A foot-supporting arch may be added in some cases, but we prefer a balanced foot suspension, for reasons given below.

Modifications of the Thomas Splint.—The best known of these is the Wallace-Maybury splint. In our opinion this splint possesses no advantages over the original pattern, and has certain definite shortcomings. It is expensive and cumbersome. The side bars are so massive that no bending of them is practicable. The rectangular fixed position of the foot which the splint imposes is unsatisfactory, for the following reasons: (1) The right-angled position of the foot increases the tension on the gastrocnemii, and so

tends to increase any flexion of the lower fragment; (2) The fixation of the foot impedes the maintenance of function in the lower part of the leg during treatment.

Another modification was introduced by one of us (C. M. P.).[7] It is made from the standard aluminium splinting, and was designed for transport. Its malleable crutch makes it serviceable for this purpose, and the prop is a useful feature. For continued treatment the splint is not sufficiently rigid to procure full extension in any but light cases.

Fig. 25.—Thomas knee splint applied, and suspended from a beam. A moulded plaster foot-piece, with balance, for cases of foot-drop, is also shown.

Details of the Hodgen Splint.—We employ the standard pattern of this splint, but do not use the original form of suspension and extension. The splint is hung from a Balkan beam (*Fig.* 26), from two adjustable levels. Extension is applied by a weight attached to the end of the splint, the attachment running over a pulley in the upright of the beam. This method has been described by Stimson[3] and Hey Groves.[8]

Details of Extension Attachment.—For both of the above-described splints we commonly use an extension attachment of the Buck type. The application is made with ordinary adhesive strapping, or by means of Heusner's glue applied to fine cotton bandaging. The latter adhesive consists of:—

Methylated spirit	..	..	50 c.c.
Benzine ..	..	..	25 c.c.
Resin (commercial)	..	..	50 grms.
Venice turpentine	..	..	5 grms.

We prefer to use ordinary adhesive strapping, as it seems less inclined to produce vesication of the skin, and when it does give way, does so gradually

and not with the completeness which is characteristic of the glue application. A stirrup or spreader wide enough to prevent pressure on the malleoli is set in the foot end of the extension unit.

Transfixion of the bone for extension purposes has a strong advocate in Major Hey Groves. The advantage common to the method in all situations is the ease with which full extension may be effected. In cases where the lower fragment of the femur can be transfixed, the method has the further advantage that the knee-joint is left free from pull or fixation, and the lower fragment can be suspended in any position. We have used transfixion pins in several cases where it was impossible to apply a Buck extension, or where a fuller control of the lower fragment of the femur was required. For the femur we

FIG. 26.—Method of suspension and applying extension in the case of a Hodgen splint.

use pointed steel pins 4 mm. in diameter, and for the os calcis similar pins 3 mm. in diameter. The pins can be readily made from steel knitting-needles of the appropriate size. In the absence of a proper drill, we hammer the nails into place, according to Wilms'[4] technique. A horseshoe bent from aluminium splinting affords the coupling for the extension, as shown in *Fig. 27*. The risk of infection has always to be borne in mind in using this method, and we do not consider it a suitable one for conditions of active service, save in exceptional cases.

Anklet extension attachments have not proved a success. We have used moulded plaster-of-Paris anklets, and also the usual leather type, and —especially with the latter—have found that sores over prominences are rapidly formed if any degree of extension is exerted.

Application of Splints.—The skeleton splints described are completed by slings. We prefer old linen for this purpose above anything; it does not stretch, and yet is easily adaptable to the contour of the limb; it is absorbent, and not irritating to the skin. Flannel has its uses for this purpose, but stretches too readily to be of full service in the healing period. Enough slings should always be used to support as completely as possible the posterior surface of the limb; they should be so arranged about the fracture, that when the dressing slings are removed, both fragments are still held in place by others. Zinc troughs in place of slings do not appear to have much to recommend them; unless they are very carefully applied they are liable to cut the skin

Fig. 27.—Transfixion of lower end of femur in a case of subtrochanteric fracture, and suspension with a weight of 20 lb. at a right angle.

at their margins; moreover, they render the posterior surface of the thigh inaccessible.

The extension is attached to the splint by a strap passing over the notch in the splint and the stirrup of the extension (see *Fig.* 28). This method gives a simple extension which is easily regulated. We consider the method of tying the extension strips round the end of the splint, advocated by Lieutenant-Colonel Jones,[1] to be unsatisfactory for gunshot fractures; in our experience it has not been possible or even desirable to obtain full extension at the time the splint is first applied. If this is admitted, some adjustable form of attachment must be supplied, and the strap system answers the purpose as efficiently as the more elaborate and slower acting screw arrangements.

After-Treatment.—During stationary treatment, the Thomas splint, as well as the Hodgen, should be suspended from a beam (*Fig.* 28). This allows more freedom to the patient, and facilitates nursing and dressing.

The maintenance of extension presents no difficulties in the case of the Hodgen splint. In the case of the Thomas, the so-called 'fixed extension' is really an elastic pull, owing to the resilience of the tissues covering the *point d'appui*, and the elasticity of the skin to which the extension is attached. This extension is kept up by tightening the strap as necessary, and in most cases the limb can be so pulled out to full length or over. Failure in this respect is usually due to intolerance on the part of the patient to the continued

FIG. 28.—A Thomas knee splint bent at the knee level for a case of fracture in the lower third of the femur. The method of strap attachment of the fixed extension is well shown.

counter-pressure. In such cases, or if a sore forms over the ischium, weight extension may be attached to the lower end of the splint, as is done in the Hodgen splint. This form of extension can be continued to the end of treatment or not, as may be convenient.

Pressure sores should not develop under the ring of the Thomas splint if the parts exposed to pressure are cleaned with spirit, powdered, and gently rubbed twice daily. It should be remembered that such sores in any part are most readily formed soon after the application of a splint, before the skin and subcutaneous tissues have adapted themselves to the new arrangements. In early transport, therefore, powerful extension should not be applied, and any complaint of the patient as to pressure should be carefully attended to.

Position of the Foot.—In both the above-described splints, if there is no paralysis, the foot should be allowed to lie in the natural position, i.e., slightly everted and plantar flexed. The patient should be encouraged to move the

foot at intervals. If the foot is left in this way, foot-drop does not develop, and union of the fragments will occur in the normal position without the inversion which is often seen in cases in which the foot has been fixed at a right-angle. It should be remembered that after a fracture below the trochanter, the upper fragment is maintained in the everted position by the action of the glutei.

Control of Foot-drop.—Some degree of paralysis of the anterior tibial group was present in 17 of the cases in our series. The best method of control seems to be to apply a plaster cast to the sole of the foot (*Fig.* 25); the toes are thus kept in position, and the whole foot is balanced by a small counter-weight acting over a pulley on the beam. This method allows of active movement at the ankle, while normally maintaining the paralyzed muscles in a lax position. Fixation of the foot to an arch or foot-board attached to the splint is not so satisfactory for prolonged treatment.

CONTROL OF BONE FRAGMENTS.

For the first week or two, in severely infected cases, the limb should rest comfortably, and no forcible effort be made to pull it out to full length; strong long-axis extension increases the tension in the aponeurotic sheath of the thigh, and so prejudices the course of the natural reaction to the infective

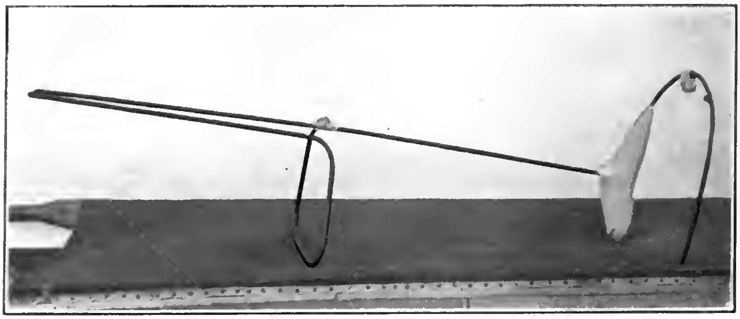


FIG. 29.—Carrier for a Hodgen splint. This has been made from a large-ringed Thomas knee splint.

process. In clean cases, or in those mildly infected, the bones should be brought into their proper position in the first week of treatment.

An x-ray examination is required before a deliberate attempt is made to aline the fragments truly. Plates taken in two planes at right angles are necessary. This is difficult to achieve in the upper third, and one may have to trust to a stereoscopic view. Captain J. N. Ferguson has taken some excellent plates for us, however, getting a lateral view of the upper part of the bone by flexing the thigh of the uninjured side, placing the plate to the outer side of the injured limb, and taking the picture from inside and below

In order to overcome the difficulty of taking x rays of patients in Hodgen's splints, we have devised a carrier (*Fig.* 29), which slings the splint in

its usual position and maintains extension. It is made from a large ringed Thomas knee splint. A carrier is required for each side. To form the carrier, the outer bar of the Thomas is cut away from the ring, and bent so as to form a wide-based high prop at about mid-leg level; the free extremity of the prop is bound to the inner bar. The ring is cut through behind, and bent so as to form an arch which passes around and above the upper extremity of the Hodgen splint. To prepare the patient for transport, the upper arch of the Hodgen is suspended from the central part of the carrier arch. The lower part of the Hodgen rests on the narrower extremity of the carrier (*Fig.* 30). A strap is then passed round the end of the Hodgen and the notch in the carrier, and tightened till the 'fixed extension' so effected equals the weight extension, the upper *point d'appui* being formed by the inner leg of the arch of the carrier abutting on the perineum. The weight is then detached from the Hodgen splint, and the patient is ready for removal.

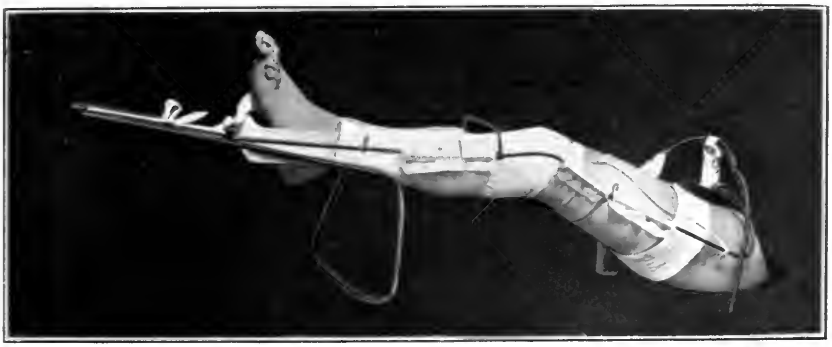


FIG. 30.—The Hodgen carrier in use. The splint is suspended from the arch of the carrier above, and rests on the lower part. 'Fixed' extension is effected by means of a strap, the inner limb of the arch of the carrier exerting counter-pressure in the perineum.

Measurement of the limb is important, but it does not reveal flexural displacements of the fragments.

Principles Determining the Reduction of Displacement of Fragments.—Long-axis traction is undoubtedly the main factor which determines the return of the fragments to their natural position. Its first action is to disentangle the ends of the fragments from the surrounding tissues, and to draw the ends apart so that they can move independently of one another. Its second action is to increase the tension within the fascial sheath of the limb; the tension produces a circumferential force acting on the freed bone ends, and tends to push them back into their normal place, where they occupy the least space.

The displacement of the fragments is due to: (1) The force of impact of the missile; (2) The forces acting as the patient falls; (3) The tonic action of muscles on the fragments after the normal balance of muscular action has been destroyed by the loss in skeleton continuity.

The displacement due to the first two causes is controlled once the bone ends are disentangled by long-axis traction. That due to muscle tone will

continue to produce a certain displacement, unless: (*a*) A sufficient reducing force can be applied, either through tension produced by long-axis traction, or by the direct action of pads acting from an outside mechanism; (*b*) The joint on which the muscle acts is so placed that the latter becomes completely relaxed.

In dealing with the *lower half* of the femur, flexion of the lower fragment (except in impacted cases) is constantly observed; the muscles, acting unopposed, which produce the displacement being the gastrocnemii and short

Fig. 31.—Showing the extreme flexion of the lower fragment in a supracondylar fracture. Long-axis extension failed to effect replacement.

head of the biceps. If the fracture be towards the middle of the bone, the reducing forces will be acting as a long lever against the muscle tone, and so reduction of the displacement is easily effected; in practice, the use of the Thomas knee splint gives excellent alinement in the middle third fractures. As the fracture gets nearer and nearer the condyles, so the leverage through which the reducing force acts diminishes, till, in a true supracondylar fracture, the lower fragment may be sharply flexed (*Fig.* 31) and no degree of long-axis traction will have any reducing effect upon it.

The same principles apply to displacements in the *upper half* of the femur. The almost constant displacement in the upper third is flexion due to the unopposed action of the ilio-psoas, and abduction and external rotation caused by the gluteal muscles. In fractures at the junction of the upper and middle thirds of the thigh, long-axis traction has some reducing force; but in the subtrochanteric area it exerts little or none.

In support of the above statements the following clinical observations may be quoted: In the 51 cases of fracture in the lower third of the femur in our series, we have observed flexion of the lower fragment in 47; in the remaining 4 the fragments were impacted. The flexion has never been completely corrected by long-axis traction in a straight Thomas knee splint. If the finger be passed into the wound on to the top of the lower fragment when the leg is under forced extension in the extended position no reduction of the flexion can be felt to take place beyond a limited point, however great the weight applied; the flexion is felt to be greater when the foot is held at a right angle than when it is allowed to drop, and the flexion of the fragment can be at once increased by powerful dorsiflexion of the foot.

TECHNIQUE OF REDUCTION.

Lower Third of the Femur.—If the case is a clean one, alinement may be obtained at once, and the limb put, after extension, in a bent splint as described below. In general, however, we treat infected cases for two

Fig. 32.—Arrangement for exerting weight extension during operation or application of plaster appliances.

or three weeks on a straight Thomas splint. During this period the wound infection will have settled, and by keeping the strap acting on the extension stirrup tight, the limb will have been pulled out to full length. At this stage x-ray plates in two planes will shew what has to be done. A prophylactic dose of antitetanic serum is given two days before manipulation.

In a few cases anæsthesia may be unnecessary, the fragments practically 'hinging' into position on flexion of the leg at hip and knee. As a rule it will be necessary to put a finger on the wound, to determine the position of the fragments and to guide them into place. Over-extension with a weight (up to 90 lb.), by means of the appliance shown in *Fig.* 32, is effected when free disentanglement of the fragments is required. Sometimes the removal of the tips of the fragments with bone pliers may enable otherwise obstinate

Fig. 33. Fracture in lower third of the thigh, showing flexion of the lower fragment uncorrected by long-axis extension in a Thomas splint.

Fig. 34.—The same case after manipulation and fixation in a Thomas splint bent at the knee.

cases to fall into line. At the completion of the manipulation, the fragments should be in one of three positions, viz. : (1) Impacted (*Figs.* 33, 34); (2) Loosely opposed end to end (*Figs.* 35, 36, and 37, 38); (3) Opposed side to side parallel (*Figs.* 39, 40). The last condition must be admitted a failure, and should only occur when the reduction is undertaken too late.

The manipulation having been completed, the limb is kept flexed and extended by an assistant while a Thomas knee splint, bent at an angle of about 45° at or just above the knee level, is applied. The position of the

slings about the fracture requires attention. Two narrow 'fixation' slings of folded linen are applied so as to support the fragments near their ends: that opposing the flexion of the lower fragment is the most important. These two slings should remain constantly in position until consolidation of the fracture has commenced. A 'dressing' sling which controls the wound is applied between the two fixation slings. Extension is applied by a strap as described above, or by means of a weight if more convenient.

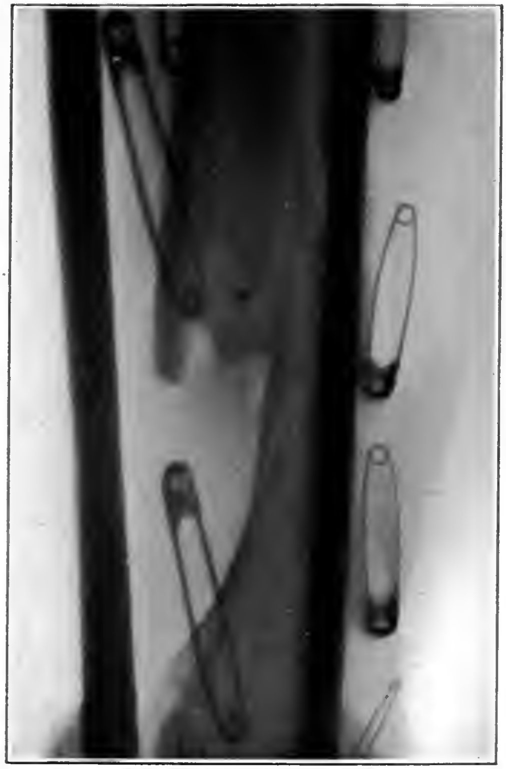


Fig. 35.—Fracture in lower third of the thigh: flexion of the lower fragment not reduced by being pulled out over-length in a Thomas splint.

Fig. 36.—The same fracture put up in the flexed position, after the removal of a bone fragment.

We have not observed any reaction after quiet reposition. When the procedures have been more vigorous, the local infective process may have flared up, but it has never been necessary to alter the position. Œdema of the foot and leg often results from sling pressure in the popliteal space: a little adjustment of sling or extension will remedy this. Sling pressure on the external popliteal nerve is dealt with below.

When the leg is in the flexed position, care must be taken that lateral angulation of the fragments does not occur. Adduction of the upper fragment

is the rule in these cases, and accounts for the tendency of the limb to fall into the position of knock-knee. The adduction results from the action of the adductor muscles, and is accentuated by the position of relative abduction assumed by the injured limb. This abduction is secondary to the tilting down of the pelvis on that side, which occurs in practically every case. If the adduction of the upper fragment is not corrected by long-axis traction, the fragment should be drawn outwards by a small padded splint applied

FIG. 37.—Oblique fracture ('concussion' type) in lower third of thigh showing persistent flexion of the lower fragment.

FIG. 38.—The same fracture put up in the flexed position, showing fair reduction of the displacement.

to the inner side of the thigh and strapped across to the outer bar of the splint; the lower fragment may be counterfixed below. This displacement is easily treated in the first few weeks of the injury, but is very difficult to control later.

The treatment of the case is continued in the bent splint till the union is firm. If any degree of impaction has been effected after manipulation, very little extension is required to maintain the position.

Middle and Upper Thirds of the Femur.—The displacement in this class

of injury can be conveniently controlled in the classical Thomas splint. Long-axis traction alone suffices to reduce the fragments. Fractures at the junction of the upper and middle third also often come into line in the same way. If, however, flexion of the upper fragment is not overcome, the methods adopted for subtrochanteric fractures will apply.

Subtrochanteric Fractures.—The upper fragment is in most cases abducted and flexed. The displacement in both directions may be extreme. When the lesser trochanter is detached from the main fragment, the displacement

FIG. 39.—Fracture in lower third of the femur, incompletely pulled out on account of the nature of the wounds: marked flexion of lower fragment.

FIG. 40.—The same fracture put up in flexion four weeks after the injury. Correct replacement has not been obtained, but the fragments now lie parallel.

does not occur: and in one instance (*Case* 118), though the lesser trochanter was intact, the lower fragment lay in front of the upper. The lower fragment is usually adducted, or appears to be relatively so.

The upper fragment is quite uncontrollable, and so the aim must be to aline the lower with it as far as possible. A Hodgen splint, employed as described above, is effective in many cases; the important points are to flex the thigh as far as possible, and to arrange a sling to bring the upper end of the lower fragment well forward.

Transfixion of the lower fragment just above the condyles can be of great value in these cases. With fractures at this level, the procedure involves the minimum risk of infection, and renders possible the complete control of the lower fragment. In *Case* 115, adopting this procedure, the thigh was held at a right angle to the body in order to aline the fragments (*Fig.* 27). The limb was maintained in this position for five weeks, and then gradually allowed to drop to the normal.

COMPLICATIONS.

Nerve Injury.—Eleven cases of primary nerve injury were observed in this series. The great sciatic was involved in 6, the external popliteal in 4, and the anterior crural in 1.

Secondary paralysis or paresis in the distribution of the external popliteal occurred in 7 cases, in all but one of which it cleared up within six weeks. The lesion appeared to be due to sling pressure on the nerve in all these cases. The level at which the pressure is most often exerted is near the head of the fibula, but in two cases it seemed probable that the effect was produced in the supracondylar area. This complication should be avoided by leaving the areas mentioned free from pressure as far as possible, or at any rate by relieving it as soon as subjective signs are complained of in the distribution of the nerve in question.

In *Case* 112 complete paralysis of the sciatic nerve developed in the sixth week. The case was one of fracture at the junction of the upper and middle thirds of the bone; the paralysis was possibly due to sling pressure on the nerve over the prominent upper end of the lower fragment.

Treatment during the period under review is limited to control of the foot and the maintenance of the nutrition of the affected muscles by massage. The method used for balancing the foot is detailed above, and illustrated in *Fig.* 25.

Injury to Arteries.—*Primary damage to the main vessel* was noted in 3 cases of the series. In 2 cases the injury was due to rifle-bullet wounds which did not become infected. In *Case* 10 a diffuse aneurysm formed in the lower part of the thigh; the pulsation in this gradually decreased, till at the end of four weeks it was localized to an area the size of a halfpenny. In *Case* 68 an arterio-venous aneurysm formed in the lower end of the common femoral; the size of the swelling diminished during the month the patient was under observation; but ligature of the artery was found to be necessary later, and was carried out in England. In *Case* 59 a shell fragment entered the front of the thigh in the middle line one inch above the upper border of the patella; the missile perforated the femur just above the condyles, and after notching the popliteal artery, lodged under the skin. A progressive painful hæmatoma formed, threatening the nutrition of the leg. Five days after injury the missile was removed, the clot turned out, and the popliteal artery and vein were tied on either side of the injury. The patient made an uninterrupted recovery, without damage to the foot or infection of the knee-joint.

Exposure of the main vessels in the primary wound was noticed in 18 cases; in 5 of these hæmorrhage occurred later.

Secondary hæmorrhage occurred in 17 cases, with 2 deaths. The average time after injury when it occurred was nineteen days, the shortest period being eight, and the longest fifty-one; in the latter case bleeding was definitely due to a sharp fragment perforating the popliteal artery after the changing of a splint. In 6 the bleeding was from the main vessel. The treatment adopted for these cases was amputation in *Cases* 20 and 26, followed by recovery. In the remaining four (*Cases* 33, 39, 111, and 112), the vessel was tied in the wound: the first two died shortly after operation, the others recovered. The bleeding was apparently from minor vessels in 11 cases. Hæmostasis was effected by ligature of the vessel in 2 cases and dry packing in 9. Recurrence occurred in two of the latter cases, and was finally controlled by clamping the bleeding area with artery forceps, which were left *in situ* for three days.

Standard Treatment.—A tourniquet is applied in the first instance; this should not be left on for more than half an hour. As soon as possible afterwards, the patient is anæsthetized and search made for the bleeding point. A good view of the whole wound must be obtained, and any part where fragments may impinge on the main vessels should be especially inspected. If the bleeding vessel can be found, it is ligatured as near as possible to the aperture; if it is necessary to tie the popliteal artery, the vein should also be included. If no vessel is found, a dry gauze pack of the whole wound track is the only resource. The pack should be removed as soon as suppuration has rendered it easily movable—its longer retention will only encourage recurrence of bleeding. Recurrent hæmorrhage appears to be commonly due to failure to locate a fair-sized opening in a vessel at the first inspection.

Osteitis.—In all infected cases some involvement of the bone must be present, but the frequency with which signs of osteomyelitis rapidly pass off is remarkable. In this series, 30 cases of persistent pyrexia were attributed to bone infection; the other less common cause of the condition being a slow-spreading cellulitis with intermuscular abscess formation.

In most cases *x*-ray examination showed definite rarifying osteitis in the region of the fracture, with irregular sequestration. In *Cases* 16 and 46 the fracture was oblique, and the fractured surfaces were separated to the extent of nearly half an inch. A long cavity was thus formed lined with granulating tissue. An operation, entailing full opening of this cavity and packing it with gauze, led to a prompt subsidence of the pyrexia, and to progressive healing, with no apparent probability of sequestrum formation.

Sequestrum Formation.—In the majority of septic cases there is some necrosis of the tips of the main fragments of the bone, as well as of detached pieces. *X* rays (especially stereoscopic views) exhibited the presence and position of dead bone very clearly at a period from six weeks to two months after the injury.

In this series we have removed sequestra from 23 cases at an average period of about two months from the primary injury. It is true that

secondary operations for the same purpose may be necessary, but by no means in all cases. The operation is more easily carried out at this time, before a massive involucrum has formed, and limits the amount of reactive inflammation. Seven weeks was the earliest date after injury at which complete separation of sequestra from the main fragments was noted.

Technique of Operation.—A prophylactic dose of antitetanic serum should always be given. The dead fragments are localized as accurately as possible by means of *x* rays and the probe. The structures are then cleanly divided down to the bone, and the sequestra removed with forceps. No aimless curetting is performed, as this is liable to light up the infective process and to further bone necrosis. The cavity left after removal of the bone fragments is packed with dry gauze for a few days.

Some pyrexia and local œdema were observed in 6 cases after operation, and in 4 cases a sharp attack of erysipelas occurred. Prophylactic vaccination against streptococcal infection had not been employed in any of these cases.

Tetanus.—There were five cases in this series. In two (*Cases* 9 and 97) the symptoms appeared on the sixteenth and fourteenth days respectively, and remained localized to the thigh muscles. Both recovered. In the other three (*Cases* 32, 94, and 110), the symptoms were general from the commencement, and the results fatal. Symptoms commenced forty-four, forty-five, and fifty-four days after injury respectively. In the last-mentioned case some local spasm, which soon passed off, was noticed six days after primary injury; in the second general attack all signs of tetanus had subsided eight days before death, which was due to streptococcal septicæmia, the organism being recovered from the blood. These three cases all received antitetanic serum shortly after they were wounded, but no further injections before the onset of symptoms. It is now customary to give a prophylactic dose of serum every fourteen days while the wounds continue to discharge, and in all cases before any operation or manipulation is undertaken.

Amputations.—In four cases of this series amputation was done. In two (*Cases* 20 and 26) it was performed for secondary hæmorrhage from the main vessel: both recovered. In *Case* 27 the femur was broken at two levels and the knee-joint became infected: recovery took place. In the last (*Case* 24), amputation was performed on the thirteenth day for spreading gas gangrene, with a fatal result.

Massage and Movement.—This cannot be carried out in a thorough way during the period under consideration. The desirability of leaving the foot free has been mentioned above. Movement at the knee-joint can only be practised in cases in which the lower fragment has been transfixed for extension purposes. The whole limb should be massaged as far as the splintage permits in all cases, once they run an afebrile course.

Union.—We have not been able to observe completed union in many cases of this series, but the general table at the end defines the condition, as far as possible, on transfer. Most rapid consolidation was observed in those cases in which there was much local comminution and no infection. Several cases in which there was considerable loss of substance showed remarkable

bone formation within two or three months. *Case* 8 is a good example of this (*Figs.* 41 and 42). The most evident cause militating against bone union is severe infection; mild local continued infection does not appear to hinder the process to any great degree, though it sometimes leads to an excessive inflammatory deposit of weak osseous material.

Ambulatory Treatment.—Whenever the condition and position of the wounds allow, the provision of some apparatus which permits the patient to get about is of inestimable value. The morale of the man rapidly improves, and the wound healing and bone union progress correspondingly.

Fig. 41.—Fracture in the middle of the femur one month after injury. Good position. The length was normal. Absence of half to one inch of compact bone is shown.

Fig. 42.—The same fracture three months after injury. Considerable new bone formation has taken place.

We have employed an ambulatory appliance[6] in 13 cases of this series. It was applied on an average about two months after the primary injury. In simple cases the apparatus can be used at a much earlier stage, but for infected gunshot cases there should be no pyrexia, and sound commencing union should be present before it is applied.

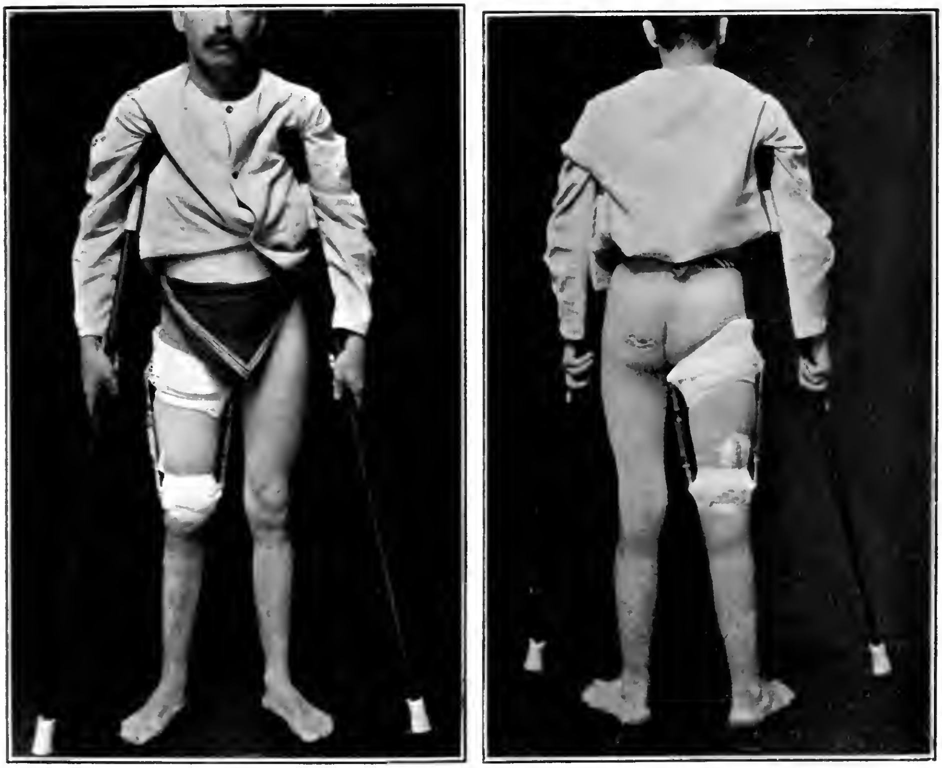
The form of the ambulatory apparatus is shown in *Figs.* 43 and 44; the technique of its application is dealt with elsewhere.[6] It consists of two

moulded plaster-of-Paris collars which are united by two extension screws, on the principle of Hackenbruck's Distraktions-Klammer.[5] The apparatus leaves the knee-joint free, and is easily applied by the surgeon.

SUMMARY.

1. The Thomas knee splint is the most suitable apparatus available for use in the transport of cases of fracture of the femur.

2. The same splint can give excellent results as regards alinement and length in fractures in the middle third of the femur.



FIGS. 43, 44.—Front and back views of ambulatory appliance. The ischial saddle and supracondylar collar are made with plaster of Paris. The two extension screws are set in perforated zinc arches.

In the case illustrated the apparatus was applied two months after injury.

3. Good alinement cannot be attained by the use of the Thomas splint in the case of fractures occurring in the lower third of the femur; but if the splint be modified by bending it at the knee-joint level to form a skeleton double inclined plane, the results are good.

4. Fractures in the upper third of the femur can generally be well treated in a Hodgen splint.

5. Adhesive extension attachments are satisfactory for most cases, and are well suited to the conditions of active service.

6. Transfixion of the bone is useful in special cases, and when the procedure is carried out at a distance from an infective focus.

7. This series of cases demonstrates the importance of periodical prophylactic injections of antitetanic serum.

In conclusion, we wish to acknowledge our indebtedness to Captain J. N. Ferguson, R.A.M.C., for the patience and skill he has expended in taking a large number of x-ray photographs and in the preparation of the figures published with this paper.

FATAL CASES.

The following table gives the cause of death, which took place in 10 cases of the series of 125.

Case No.	Cause of Death	Injury	Days between Injury and Death
24	Gas gangrene	Fracture in lower third, injury of knee-joint, amputation	14
29	Septicæmia	Comminution of whole upper third of femur	10
32	Tetanus	Fracture at junction of lower and middle third	45
38	Secondary hæmorrhage from external circumflex at its origin	Subtrochanteric fracture	11
39	Secondary hæmorrhage from profunda femoris	Comminution of whole of upper third of femur: diarrhœa	11
43	Gas gangrene	Fracture of both femurs	4
42	Gas gangrene	Fracture in upper third of femur	6
66	Peritonitis and pelvic cellulitis	Fracture of neck of femur: gunshot wound of bladder	12
94	Tetanus	Fracture in middle third of femur	53
110	Septicæmia (streptococcal) following tetanus	Fracture at junction of middle and lower third of femur	78

[*See table on next page.*

TABLE OF 125 CASES OF G

This Table has been abstracted from the original notes, now filed with the National Research Commit
between receipt of wound and commencement of observation was 78·8 hours. Under the heading "Sp
Hodgen's splint = Standard Hodgen wire splint; *Thomas's splint* = Thomas knee sp

No.	Days under Observation	Position of Fracture	Comminution	Degree of Infection	Splint Treatment
1	28	Lower third	6 in., coarse, much loss of bone	Severe	Long outside for transp Thomas's splint
2	25	In upper third	5 in., coarse, not much loss	Medium	Aluminium splint
3	208	Upper and middle third	3 in., coarse	Medium	As above
4	34	Middle	Slight, oblique fracture	Medium	Thomas's splint
5	39	Lower and middle third	3 in., coarse, much bone removed	Severe	Aluminium splint bent at k
6	51	Middle	Slight, oblique fracture	Medium	Thomas's splint
7	187	Lower and middle third	Slight, oblique fracture	Medium	Aluminium splint bent at k
8	51	Middle	6 in., coarse	Clean	Thomas's splint, and am latory splint 30th day
9	46	Upper third	Slight, oblique fracture	Severe, local tetanus	Hodgen's splint
10	28	Lower and middle third	3 in., coarse	Clean	Thomas's splint
11	181	Upper and middle third (just below)	3 in., medium	Severe	Wallace's splint
12	52	Middle and lower third (just above)	4 in., great, medium	Severe	Thomas's splint
13	48	Upper and middle third	2 in., coarse	Severe	Aluminium splint
14	37	Middle	2 in., coarse, little displacement	Medium	Thomas's and ambulat splints
15	53	Lower and middle third (below)	2 in., medium	Severe	Bent Thomas's splint
16	50	Middle	Slight, oblique fracture	Medium	Thomas's splint
17	90	Sub-trochanteric	2 in., coarse	Severe	Hodgen's splint
18	21	Lower and middle third	Very slight, 'flûte en bec'	Medium	Thomas's splint
19	5	Lower and middle third	Local, slight	Medium	Thomas's splint
20	40	Lower and middle third	Moderate	Severe	Thomas's splint. Amputati

C FRACTURE OF THE THIGH.

rder in which the cases have been entered is not strictly chronological. The average period elapsing
nent," the splint mentioned is that which was finally used in obtaining and maintaining alinement.
rd pattern ; *Aluminium splint* = Modified Thomas type referred to in the text.

Complications	Result	Shortening	Alinement	Union on Transfer	Remarks
—	Recovery	1 in.	Good	Slight	—
al popliteal nerve paralysis	Recovery	1¼ in.	Good	Slight	—
ent foot drop	Recovery	¾ in.	Fair	Firm	Ambulatory treatment
—	Recovery	½ in.	Good	Slight	'Concussion' fracture
—	Recovery	1¼ in.	Fair	None	Femoral artery exposed in wound ; much bone lost
—	Recovery	¾ in.	Good	Fairly firm	'Concussion' fracture
ent pyrexia from osteitis ntermuscular abscess forma-	Recovery	½ in.	Good	Firm	—
—	Recovery	¾ in.	Good	Firm	—
ent pyrexia from osteitis ; tetanus	Recovery	½ in.	Fair	Firm	Local tetanic symptoms lasted 24 days
-venous aneurysm of com- femoral	Recovery	½ in.	Good	Slight	Aneurysm decreased in size while under observation
ent temperature and œde- econdary to osteitis	Recovery	1½ in.	Fair	Firm	Tense and persistent effusion into knee-joint
ent pyrexia due to osteitis	Recovery	1½ in.	Fair	Slight	Considerable loss of bone
—	Recovery	½ in.	Good	Slight	—
—	Recovery	½ in.	Good	Slight	—
lary foot drop	Recovery	¼ in.	Good	Slight	Large explosive wound, femoral artery exposed
ia from infected bone cavity	Recovery	¾ in.	Good	Fairly firm	—
nal popliteal paralysis	Recovery	1 in.	Poor	Firm	Large explosive exit wound
ete external popliteal para-	Recovery	¾ in.	Fair	Slight	'Concussion' fracture
—	Recovery	½ in.	Good	None	—
lary hæmorrhage from fem- artery 22nd day	Amputation : recovery	—	—	—	Amputation for secondary hæmorrhage

Continued on next page.

TABLE OF 125 CASES OF GUNSH

No.	Days under Observation	Position of Fracture.	Comminution	Degree of Infection	Splint Treatment
21	120 (walking)	Upper and middle third	2 in., medium	Severe	Aluminium and ambulat splints
22	101 (walking)	Upper third	3 in., medium	Severe	Thomas's and ambulator splints
23	113 (walking)	Middle	2 in., slight; considerable loss of bone	Mild	Thomas's and ambulator splints
24	9	Lower and middle third	3 in. extreme	Severe, gas	Aluminium splint
25	15	Upper and middle third	Slight, spiral fracture	Clean	Thomas's splint
26	45	Supracondylar	2 in., extensive and fine, into joint	Severe	Aluminium splint
27	62	Upper and lower third (2 fractures)	Slight at both levels	Severe	Right, Thomas's splint; aluminium splint
28	45	Junction of upper and middle third	2 in., medium, considerable loss of bone	Severe	Aluminium splint
29	3	Trochanter and below	4 in., medium, extensive	Severe	Thomas's splint
30	64	Middle	2 in., slight, coarse	Severe	Thomas's splint; ambula splint on 50th day
31	23	Upper third and middle	2 in., coarse, moderate	Severe, anaerobic	Aluminium splint
32	42	Lower and middle third	2 in., marked, medium	Severe	Thomas's bent splint
33	6	Sub-trochanteric	Slight	Severe	Thomas's splint
34	34	Lower and middle third	2 in., coarse, medium	Moderate	Thomas's splint
35	18	Just below middle	Slight	Moderate	Thomas's splint
36	63	Upper and middle third	3 in., coarse, much	Severe	Thomas's splint
37	20	Above middle	Slight	Moderate	Thomas's splint
38	10	Middle	3 in., slight, coarse	Slight	Thomas's splint
39	7	Trochanter, great	Much, fine	Severe	Thomas's splint
40	8	Middle and lower third	Slight, coarse	Clean	Thomas's splint
41	50	Sub-trochanteric	$1\frac{1}{2}$ in., coarse, fine, medium	Severe	Aluminium splint

TURE OF THE THIGH—*continued.*

COMPLICATIONS	RESULT	SHORTENING	ALINEMENT	UNION ON TRANSFER	REMARKS
—	Recovery	1 in.	Fair	Fairly firm	One sequestrectomy; wound completely healed on transfer
—	Recovery	$\frac{3}{4}$ in.	Good	Firm	Two sequestrectomies: wound nearly healed on transfer
rsis in sciatic distribution, sed off in 7th week	Recovery	$\frac{1}{2}$ in.	Perfect	Firm	One sequestrectomy, wound healed on transfer
ling gas infection; amputa- 13th day	Amputation: death	—	—	—	Death from toxæmia 14th day
—	Recovery	$\frac{1}{2}$ in.	Good	None	'Concussion' fracture
eal artery exposed: second- hæmorrhage 25th day: ction of knee-joint	Amputation; recovery	—	—	—	Amputation for secondary hæmorrhage: knee-joint infected
ion of right knee-joint (strep- occal)	Amputation above right knee 55th day	-		—	Amputation for infection
ia persistent	Recovery	1 in.	Good	Slight	Explosive type exit wound
al toxæmia from gas and tococcal infection	Death	-	-	—	Death on 6th day
lete persistent external teal paralysis	Recovery	1 in.	Good	Fairly firm	—
nda femoris exposed in nd	Recovery	$\frac{1}{2}$ in.	Good	Slight	German
us on 44th day	Death	$\frac{3}{4}$ in.	—	—	Died in a spasm 15 hours after onset of tetanic symptoms
dary hæmorrhage from ex- l circumflex near origin, 9th	Death	—	—	—	Died 10 hours after operation for bleeding: anæmia and toxæmia
—	Recovery	None	Perfect	Slight	—
—	Recovery	None	Good	Slight	—
dary hæmorrhage from ex- l circumflex, 31st day	Recovery	$\frac{1}{2}$ in.	Fair	Fairly firm	Vessel tied in wound
—	Recovery	None	Perfect	Slight	—
—	Recovery	None	Perfect	Slight	—
atoma about profunda femo- is secondary hæmorrhage 11th diarrhœa, general toxæmia	Death	—	—	—	Death 5 hours after ligature of vessel
—	Recovery	None	Good	None	—
—	Recovery	$1\frac{1}{2}$ in.	Fair	Slight	—

Continued on next page.

TABLE OF 125 CASES OF GUNSH

No.	Days under Observation	Position of Fracture.	Comminution	Degree of Infection	Splint Treatment
42	1	Right, middle: left, lower and middle third	Right and left, moderate	Severe, local gas	Right Liston splint; l Thomas's splint
43	2	Sub-trochanteric	Moderate	Severe, gas gangrene later	Thomas's large ring splint
44	93	Middle and lower third	2 in., much, coarse	Severe	Thomas's bent splint
45	15	Sub-trochanteric	Slight	Clean	Thomas's large ring splint
46	64	Middle	Slight	Severe	Thomas's splint
47	26	Lower and middle third	4 in., gross, extensive	Clean	Thomas's splint
48	11	Middle	Slight	Clean	Thomas's splint
49	37	Middle	Slight	Severe	Thomas's splint
50	33	Upper and middle third	Slight, local	Severe	Thomas's splint
51	28	Above middle	Slight, local	Clean	Thomas's splint
52	22	Sub-trochanteric	2 in., coarse	Severe	Thomas's splint
53	68	Sub-trochanteric	Slight	Severe	Hodgen's splint
54	9	Middle	Moderate	Mild	Thomas's splint
56	64	Lower third	Slight	Severe	Thomas's bent splint
57	50	Lower third	4 in., coarse and fine; much bone lost	Severe	Thomas's bent splint
58	64	Sub-trochanteric	Moderate	Severe	Hodgen's splint
59	8	Supracondylar perforation	Perforation, with slight fragmentation	Clean	Thomas's splint
60	71	Middle and lower third	1 in., fine, and some large	Severe	Thomas's splint
61	58	Lower third	3 in., severe, some large	Severe	Thomas's bent splint
62	62	Sub-trochanteric, much of shaft below	4 in., very marked, fine and large	Severe	Thomas's splint
63	58	Below middle	5 in., coarse	Severe	Thomas's splint
64	41	Below middle	3 in., moderate, much lost	Moderate	Thomas's splint
65	21	Lower third, oblique fracture	Very little, fine	Mild	Thomas's splint
66	8	Upper third, sub-trochanteric	2 in., moderate	Severe	Hodgen's splint

ATURE OF THE THIGH—*continued.*

Complications	Result	Shortening	Alinement	Union on Transfer	Remarks
s angrene, right leg; general xmia	Death	—	—	—	Died 1 day after admission
s angrene; general toxæmia	Death	—	—	—	Died 2 days after admission
rstent temperature; osteo-yitis	Recovery	½ in.	Fair	Firm	Temperature settled after sequestrectomy
—	Recovery	—	Good	None	—
stent temperature; osteitis	Recovery	½ in.	Good	Fairly firm	Temperature settled after sequestrectomy
—	Recovery	None	Good	Slight	—
—	Recovery	½ in.	Good	None	-
—	Recovery	½ in.	Fair	Slight	—
ral artery exposed in wound	Recovery	½ in.	Good	Slight	—
—	Recovery	None	Perfect	Slight	
—	Recovery	½ in.	Fair	Slight	
aient foot-drop	Recovery	½ in.	Good	Fair	Foot-drop secondary to sling pressure
—	Recovery	None	Perfect	None	—
ural artery exposed in wound	Recovery	½ in.	Good	Firm	Large explosive exit wound
ntent temperature due to sitis	Recovery	1 in., much bone lost	Good	Slight	—
stent pyrexia	Recovery	½ in.	Good	Fairly firm	Pyrexia probably due to bone infection; sequestrectomy
pteal artery cut laterally	Recovery	—	Perfect	Incomplete fracture	Popliteal artery and vein tied on 5th day: uncomplicated
erstent pyrexia from osteitis	Recovery	1 in.	Fair	Firm	Temperature settled after sequestrectomy
erstent pyrexia due to osteo-litis	Recovery	½ in.	Good	Fair	As above
—	Recovery	½ in.	Fair	Fairly firm	—
ral artery exposed in wound	Recovery	1 in.	Good	Slight	Considerable loss of bone
ral artery exposed in wound	Recovery	½ in.	Good	None	—
—	Recovery	None	Fair	Slight	—
ond of bladder; urinary fistula high	Death	—	—	—	Death due to toxæmia secondary to peritonitis and pelvic cellulitis

Continued on next page.

TABLE OF 125 CASES OF GUNSH

No.	Days under Observation	Position of Fracture	Comminution	Degree of Infection	Splint Treatment
67	29	Lower third	Moderate, local	Mild	Aluminium splint
68	32	Sub-trochanteric	3 in., moderate	Moderate	Thomas's splint
69	38	Upper third	Slight, local	Moderate	Thomas's splint
70	58	Lower and middle third	3 in., coarse	Severe	Aluminium bent splint
71	45	Sub-trochanteric	2 in., coarse	Severe	Thomas's bent splint
72	30	Sub-trochanteric	2 in., fine, and some large	Severe	Hodgen's splint
73	82	Upper third	3 in., coarse	Severe	Thomas's splint
74	35	Lower third	Slight, 'flûte en bec'	Mild	Thomas's bent splint
75	36	Supracondylar	Slight, impacted	Severe	Thomas's splint
76	35	Middle	None, 3 in. oblique fracture	Mild	Thomas's splint
77	34	Right, lower third; left, lower third	2 to 3 in., coarse, both sides	Both clean	Aluminium splint
78	74	Sub-trochanteric	Whole upper third, fine and coarse, exceptional	Severe	Hodgen's splint
79	26	Lower third	None, 4 in., oblique	Mild	Thomas's splint
80	36	Supracondylar, an inch above	$1\frac{1}{2}$ in., coarse	Mild	Thomas's bent splint
81	50	Middle third	Slight, local	Mild	Hodgen's splint
82	80	Supracondylar	None (impact fractures ?)	Severe	Thomas's bent splint
83	73	Sub-trochanteric	3 in, large	Severe	Thomas's large ring splint
84	56	Lower third	Slight, local	Mild	Thomas's bent splint
85	68	Supracondylar	1 in., slight	Mild	Thomas's bent splint
86	64	Lower and middle third	None, oblique fracture	Severe	Thomas's splint
87	48	Sub-trochanteric	4 in., much, large	Moderate	Thomas's splint
88	62	Middle	4 in., much, large	Moderate	Thomas's splint
89	63	Lower third	4 in., much, large	Severe	Thomas's bent splint
90	77	Lower third	4 in., slight, large	Moderate	Thomas's bent splint

ATURE OF THE THIGH—*continued*

Complications	Result	Shortening	Alinement	Union on Transfer	Remarks
—	Recovery	None	Good	Slight	—
te>-venous aneurysm of mon femoral	Recovery	None	Good	Slight	Typical bruit over aneurysm, which diminished in size during period of observation
ral artery exposed in missile ra	Recovery	½ in.	Good	Fairly firm	—
—	Recovery	½ in.	Good	Slight	—
itation of left arm for gas rene	Recovery	None	Perfect	Fair	—
ie trunk exposed; partial ysis in its distribution	Recovery	2 in.	Bad	None	Irreducible flexion and abduction of upper fragment
ot fracture patella and infection of knee on same side	Recovery	2 in.	Good	Firm	Extension impossible on account of knee infection
—	Recovery	½ in.	Perfect	Slight	'Concussion' fracture
e nerve and popliteal artery sed, no foot-drop	Recovery	None	Perfect	Slight	Impacted fracture
—	Recovery	½ in.	Good	None	—
—	Recovery	None	Fair on both sides	Fairly firm	—
drop secondary to sling ure	Recovery	½ in.	Good	Slight	Foot-drop passed off in five weeks
—	Recovery	½ in.	Perfect	Fair	'Concussion' fracture
—	Recovery	None	Perfect	Fairly firm	Fracture impacted after manipulation
dary hæmorrhage from perring branch of profunda 8th a	Recovery	None	Perfect	Slight	Vessel tied in wound, no recurrence
—	Recovery	½ in.	Good	Fairly firm	'Concussion' fracture
dary hæmorrhage from small el 15th day	Recovery	½ in.	Fair	Firm	Wound packed for bleeding; no recurrence
—	Recovery	None	Good	Firm	—
—	Recovery	None	Good	Firm	—
lete paralysis in distribution xternal popliteal nerve	Recovery	½ in.	Good	Firm	'Concussion' fracture
—	Recovery	None	Fair	Fairly firm	—
—	Recovery	None	Perfect	Firm	—
tent pyrexia due to recurrent ss formation	Recovery	None	Good	Fairly firm	Three operations for local abscess
—	Recovery	½ in.	Good	Firm	—

Continued on next page.

TABLE OF 125 CASES OF GUNS

No.	Days under Observation	Position of Fracture.	Comminution	Degree of Infection	Splint Treatment
91	60	Lower third and middle	2 in., slight, large	Severe	Thomas's splint
92	63	Middle	3 in., coarse, moderate	Severe	Thomas's splint
93	68	Middle	3 in., coarse, slight	Severe	Thomas's splint
94	53	Upper third	4 in., much	Severe, tetanus	Hodgen's splint
95	52	Sub-trochanteric	3 in., coarse	Severe	Hodgen's splint
96	100	Lower third	3 in., much, coarse	Severe	Thomas's bent splint
97	34	Middle	4 in., coarse	Moderate	Thomas's splint
98	51	Upper third	3 in., coarse	Moderate	Hodgen's splint
99	39	Middle	None, oblique fracture	Moderate	Thomas's splint
100	28	Lower third, oblique	None	Moderate	Thomas's splint
101	65	Lower third (practically supracondylar)	3 in., coarse	Severe	Thomas's bent splint
102	60	Lower third to middle	3 in., moderate	Severe	Thomas's splint
103	31	Lower third (practically supracondylar)	2 in., coarse, slight	Moderate	Thomas's bent splint
104	74	Sub-trochanteric	2 in., moderate	Severe	Hodgen's splint
105	60	Upper third and middle	2 in., moderate	Moderate	Thomas's splint
106	84	Middle	4 in., coarse and fine	Moderate	Thomas's bent splint
107	114	Supracondylar	2 in., much, medium	Mild	Thomas's flexed and am tory splints
108	68	Sub-trochanteric	3 in., medium	Severe	Hodgen's splint
109	85	Middle	1 in., slight	Severe	Thomas's bent and ambul splints
110	77	Lower third, 2 in. above condyles	2 in., moderate	Severe, tetanus	Thomas's bent splint
111	90	Lower third	Slight, local	Severe	Thomas's bent splint

[FRA]CTURE OF THE THIGH—*continued.*

Complications	Result	Shortening	Alinement	Union on Transfer	Remarks
[Secon]dary hæmorrhage from small [vess]el 12th day	Recovery	None	Good	Fairly firm	Wound packed for bleeding; no recurrence
[Fem]oral artery exposed in wound: [pers]istent pyrexia due to osteitis	Recovery	$\frac{1}{2}$ in.	Good	Fairly firm	—
[Pers]istent pyrexia due to inter-[mus]cular abscess formation	Recovery	None	Good	Fairly firm	—
[Tet]anus on 44th day	Death	—	—	—	Death from exhaustion 9 days after onset of tetanus
—	Recovery	None	Good	Fairly firm	—
[Pers]istent pyrexia from subacute [cel]litis and intermuscular abs-[cess] formation	Recovery	$\frac{1}{2}$ in.	Good	Firm	—
[Comp]lete division of sciatic nerve; [lo]c. tetanus 14th to 21st days	Recovery	None	Good	Slight	No recovery in sciatic nerve while under observation
—	Recovery	None	Good	Fairly firm	—
—	Recovery	None	Perfect	Firm	'Concussion' fracture
—	Recovery	None	Good	Fairly firm	—
—	Recovery	None	Good	Slight	—
[Pers]tent pyrexia due to osteitis	Recovery	$\frac{1}{2}$ in.	Fair	Fairly firm	—
—	Recovery	$\frac{1}{2}$ in.	Good	Slight	—
[Pers]tent pyrexia from osteitis	Recovery	$\frac{1}{2}$ in.	Good	Firm	Temperature settled after sequestrectomy
—	Recovery	None	Good	Firm	Transfixion extension
[Comp]lete foot-drop (primary), re-[cov]ered in 4 weeks	Recovery	$\frac{1}{2}$ in.	Good	Firm	—
[Kne]e joint perforated	Recovery	None	Perfect	Firm	Impaction of fragments after manipulation
[Secon]dary hæmorrhage 14th day [fro]m external circumflex	Recovery	$\frac{1}{2}$ in.	Fair	Fair	Hæmorrhage controlled by clamp after failure of pack: no recurrence
[Secon]dary hæmorrhage 10th day [fro]m small vessel	Recovery	None	Perfect	Fairly firm	Bleeding controlled by pack; no recurrence
[Scia]tic paralysis; tetanus 54th [day]; streptococcal septicæmia	Death	—	—	—	Death from septicæmia 9 days after tetanic symptoms had subsided
[Secon]dary hæmorrhage from popli-[teal] artery 51st day	Recovery	$\frac{1}{2}$ in.	Good	Fairly firm	Popliteal artery and vein tied for bleeding: uncomplicated; no recurrence

Continued on next page

TABLE OF 125 CASES OF GUNSH

No.	Days under Observation	Position of Fracture.	Comminution	Degree of Infection	Splint Treatment
112	160	Upper third and middle	Slight, local	Severe	Hodgen's splint
113	100	Middle	3 in., coarse	Severe	Thomas's splint
114	101	Lesser trochanter detached	2 in., coarse	Severe	Hodgen's splint
115	120	Sub-trochanteric	Local	Moderate	Suspension at a right an
116	89	Sub-trochanteric	3 in., coarse	Severe	Hodgen's splint
117	90	Sub-trochanteric	3 in., moderate	Severe	Hodgen's splint
118	110	Sub-trochanteric	4 in., coarse, much	Severe	Hodgen's splint
119	100	Lower third and middle	2 in., coarse	Moderate	Thomas's bent splint
120	100	Lower third; 'concussion' fracture	Local, slight	Mild	Thomas's bent splint
121	110	Upper third and middle	Local, slight	Severe	Hodgen's splint
122	90	Sub-trochanteric	Local, slight	Severe	Hodgen's splint
123	72	Lower third	Local, slight	Mild	Thomas's bent splint
124	90	Sub-trochanteric	1 in., medium	Severe	Hodgen's splint
125	45	Middle	1 in., fine	Mild	Hodgen's splint

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[1] LIEUT.-COL. ROBERT JONES, "The Mechanical Treatment of Fractures under War Conditions," *Brit. Med. Jour.*, 1916, Dec.

[2] MAJOR E. W. HEY GROVES, "The Treatment of Fractures of the Femur," *Brit. Jour. Surg.*, 1916, April, and elsewhere.

[3] STIMSON, *A Treatise on Fractures and Dislocations*, 7th ed., 1913, pp. 103 and 394.

[4] WILMS, quoted by STEINMANN in *Die Nagelextension der Knochenbrüche*, Stuttgart, 1912.

ATURE OF THE THIGH—*continued.*

Complications	Result	Shortening	Alinement	Union on Transfer	Remarks
...rent secondary hæmorrhage: ...dary persistent sciatic ...lysis; erysipelas	Recovery	½ in.	Good	Slight	Hæmorrhage four times—33rd, 42nd, 49th, and 52nd days; profunda femoris tied on last occasion
...dary hæmorrhage 15th day ... small vessel	Recovery	½ in.	Good	Slight	Bleeding controlled by pack: no recurrence
—	Recovery	½ in.	Fair	Firm	—
...lete paralysis in distribution ...iatic nerve	Recovery	None	Good	Fairly firm	Extension by transfixion
—	Recovery	1 in.	Fair	Fairly firm	Much loss of bone
...tent secondary foot-drop: ...dary hæmorrhage 21st day	Recovery	½ in.	—	Fairly firm	Bleeding controlled by pack: no recurrence
—	Recovery	None	Good	Firm	—
...dary hæmorrhage 14th day ... small vessel	Recovery	None	Fair	Firm	Bleeding controlled by pack no recurrence
—	Recovery	None	Good	Firm	—
...dary hæmorrhage 9th day ... small vessel	Recovery	None	Fair	Fairly firm	Bleeding controlled by pack: no recurrence
...ema secondary to chest ...nd	Recovery	None	Good	Fairly firm	—
—	Recovery	None	Good	Fairly firm	—
...dary hæmorrhage from small ...el	Recovery	None	Fair	Slight	Bleeding controlled by pack; no recurrence
...d of spine; cauda equina ...n; incontinent	Recovery	None	Perfect	Fair	At one period the thigh was overpulled 1 in.; cauda lesion recovering

[5] Hackenbruck, "Zur Ambulanten Behandlung von Knochenbrüchen mittels Distraktions-Klammern," *Münch. med. Woch.*, lix, 1487.
[6] Captain C. Max Page, "An Ambulatory Apparatus for Fractures of the Femur," *Brit. Med. Jour.*, 1917.
[7] Captain C. Max Page, "The Transport of Cases of Fractured Thigh," *Brit. Med. Jour.*, 1915, July.
[8] Major Hey Groves, *On Modern Methods of Treating Fractures*, Bristol, 1916.

SOME SPLINTS FOR THE TREATMENT OF GUNSHOT FRACTURES OF THE LONG BONES.

By J. HOGARTH PRINGLE, Glasgow.

If any one opinion can be formed regarding the treatment of fractures of the long bones caused by gunshot injury during the course of the war, it is that surgeons have found the methods usually employed in civilian practice not satisfactory, and especially would this appear to have been the case in dealing with fractures of the single bones—the humerus and femur. Almost constantly comminuted, with extensive lacerations of the surrounding muscles, a large number of them septic in the highest degree, it is essential that any method of treatment, to be efficient, should afford effective support; and, by whatever means this is provided, there must also be free access to the wound, which requires continual dressing, whether that be by irrigation or by the application of absorbent materials.

SPLINTS FOR THE LOWER EXTREMITY.

For the treatment of fractures of the femur caused by gunshot injury, the Thomas knee splint has been extensively advocated, and, I believe, made use of. I readily admit that this splint is a very excellent appliance in the condition which it was originally designed to treat—namely, chronic disease of the knee-joint, the rather special feature of which is that re-application of the dressing, as well as of the splint itself, is only required at long intervals. As far as my experience enables me to form any opinion on the subject of septic gunshot fractures of the femur, the Thomas knee splint seems unsuited for anything more than the most temporary treatment of these injuries. I think all the cases of this nature that have come under my care have been sent me with a Thomas knee splint applied as the means of fixation of the fracture; I will only say that it has been altogether unsatisfactory, and that my endeavour has always been to get rid of it at the earliest opportunity.

The form of splint I have employed for my cases of septic gunshot fractures of the lower limb is one I have used in treating some of the open septic fractures that are met with in civilian hospital practice, and with which I have to deal so frequently at the Glasgow Royal Infirmary. There I often have to treat cases which it is impossible to make aseptic, but I nevertheless fix them by some means, plating or wiring (as described in my paper, "Analysis of 230 Cases of Open Fracture treated by Operative Methods," *Brit. Jour. of Surg.*, ii, 102), leave the wound or wounds open, and dress them regularly and often; I remove the plate when consolidation of the tissues around is sufficient to hold the fragments of bone in position. *Fig.* 45 shows a window cut in a splint of this kind to allow access to the wound in a

case of open fracture of the femur that was treated on these lines. The patient in question wore this splint for seven weeks consecutively. The dressings were carried out with ease, and without any disturbance of the patient or his fractured bone, and solid union was obtained, with a useful limb.

My first experience of a septic gunshot fracture of the femur occurred in May, 1915, when a man was sent on to the Glasgow Royal Infirmary from France, where his left lower limb had been amputated through the upper third of the thigh, and he had also a highly septic comminuted fracture of the right femur just below the trochanters. The state of this thigh and the general condition of the patient were so bad, that I have no doubt, had the left limb not already been removed, I would have amputated the right one. I applied one of the splints described, modified in that it had a ring attached at its upper end in order to give a steadying effect and also to enable counter-extension to be applied. It acted most satisfactorily: no sagging of the ends of the bone fragments took place at the site of fracture; and the daily dressings, applied through the windows cut in the splint—which, until its

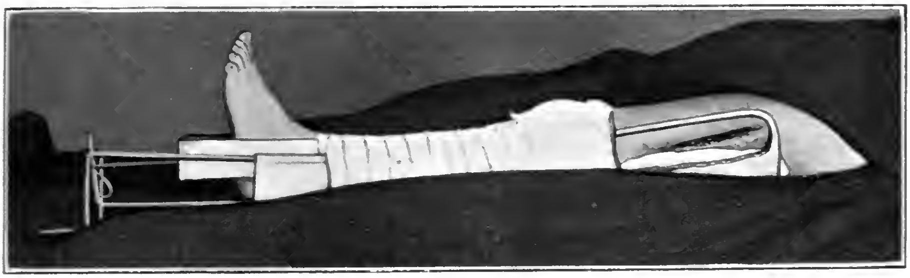

FIG. 45.—Open fracture of the femur which has been plated and the wound left unclosed. The limb is in a wire splint with a window for dressing. Light elastic extension is applied to steady the limb in the splint.

application, had been a most trying ordeal—became at once easy for the patient as well as for the dresser, and firm union of the bone was ultimately obtained.

The splints have done so well in all the cases of gunshot fractures of the limbs which have come under my care, that I hope a description of them may be of use to others who have to deal with similar cases.

I use two types of splint, one for the lower and the other for the upper extremity. The foundation of both is a skeleton of wire, made to measure for the individual patient. The splints for the lower limb are made in the form of a simple long trough. The body of the splint is made by covering the wire skeleton with lint or flannel (the former is cheaper, but a well-covered flannel splint is extremely strong), which is then impregnated with a mixture of resin and paraffin wax. When this mixture sets, as it does quickly, the body is rendered practically as hard as wood: but it can still be cut easily with a warmed knife, to make one or more windows opposite any wounds which require to be dressed. A window may also be fashioned during the making of the skeleton splint (*Fig.* 46 A), and this is a decided advantage if

a large window should be required, particularly at the back of the lower limb, because the strength of the splint is not then interfered with. The resin mixture is not absorbent, and will hold out for weeks on end.

The idea of employing paraffin wax and lint I borrowed from Sir William Macewen, who used for his excisions of the knee-joint a splint made of wire modelled for this special purpose, so that when covered with lint impregnated with ordinary paraffin wax, it constituted two gutters, one for the thigh and one for the leg. I have used this splint for almost every excision of the knee-joint that I have done, and, in my opinion, there is nothing better for the purpose. But it is not suited for the treatment of septic fractures. Lint impregnated with paraffin wax only, while admirably suited for aseptic cases, does not stand up to the constant contact with the warm and copious discharges that come from the thoroughly septic fractures resulting from gunshot

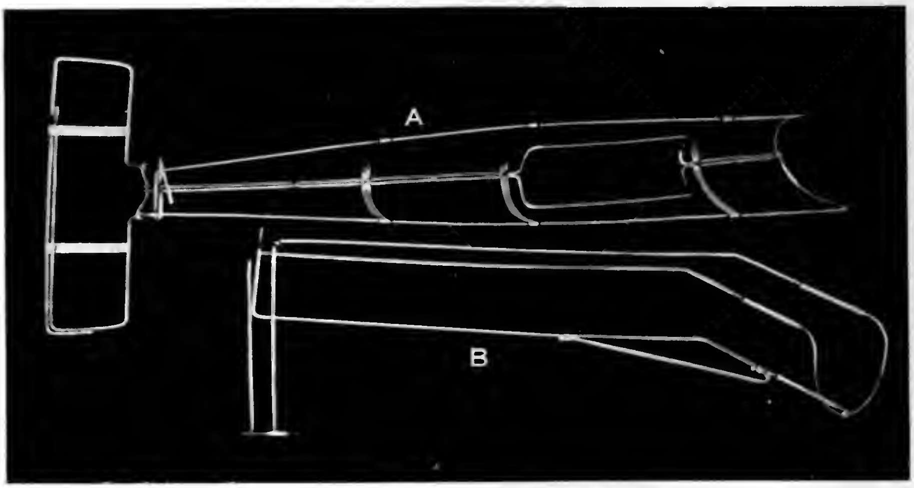

FIG. 46.—A. Skeleton splint with a large window for wound at the back of the limb. B. Telescoping angled splint. The thigh piece can be varied in length 3 inches.

injuries in this war. At present, after many trials to obtain a hard composition for stiffening the lint or flannel, I am using a mixture of resin 3 parts, hard paraffin wax 1 part, and precipitated chalk $\frac{1}{4}$ part, by weight. This mixture is taken up by the lint much better than is paraffin wax alone; it is much harder when it sets; it resists the warmth of the body and of the discharges from the wound much better than does the paraffin; and it is still quite easy to cut windows in it.

Many of the splints have been made by Messrs. Rowat & Co., Ltd., Wire Workers, Watson Street, Glasgow, to whom I am much indebted for their help and courtesy. All the splints, whether for the upper or lower extremity, which they have made for me, have fulfilled the objects I had in view to my complete satisfaction; and in this respect I am very fortunately placed, as I can have splints made to my own measurements and special instructions

regarding any modifications that may be required for a given patient, with comparatively little delay. The splints which Messrs. Rowat & Co. construct for me are made of tinned iron wire (No. 6 B.W.G.), and I have no doubt that for general purposes this material is strong enough for any limb. It is, however, a matter of the first importance that the splint shall fit the patient who is to use it, and it is a great advantage if any special feature in a case of fracture can be met in the process of making the skeleton splint. The tinned iron wire is, however, so rigid that it can only be worked, with reasonable expedition, by a practical worker; and as a substitute that could be worked by an amateur, I tried aluminium wire, and found that this material (No. 2 and No. 3 B.W.G.) could easily be turned up to make a splint that could be readily adapted to any wounds that might be present. Windows, where they are found necessary, can be fashioned during the making of the skeleton, so that the strength of the splint will not be affected. It is particularly at the back of the lower limb that a window may be required, and

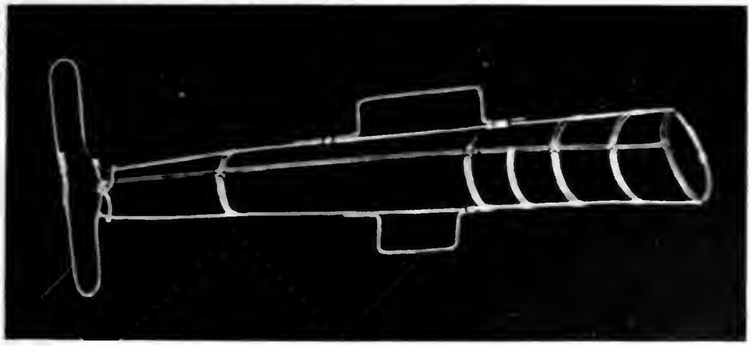

Fig. 47.—Skeleton splint with additional wires spliced to the side-bars, permitting windows to be cut in the latter.

this is easily made by shaping the back-bone, which is always necessary in splints for the lower limb, accordingly (see *Fig.* 46 A). Splints for the lower limb made of No. 2 or No. 3 gauge aluminium wire are sufficiently strong to support a limb of any weight; but to obtain the necessary rigidity, they require cross-pieces, which are made of aluminium ribbon half an inch wide and one-sixteenth of an inch thick, to hold the side bars and the back-bone together.

The disadvantage of aluminium is that one cannot solder it, so that the main part of the splint must be made out of one length of wire, and secondary pieces, like the back-bone, must be bound to the main frame; but the resulting splint is very light and strong, and the aluminium is so pliable that even when the splint is made up, it can often be manipulated to make slight alterations in its shape, which is impossible in the case of splints made of the iron wire, owing to its rigidity.

Unfortunately, it is not possible to obtain aluminium wire at the present time, owing to Government regulations, and Messrs. Rowat & Co. suggested

to me the use of galvanized iron wire. This material, even of No. 6 B.W.G., is both heavier and more rigid than aluminium wire No. 2, but it is much more easily worked than is No. 6 in the tinned iron wire. Like aluminium, it cannot be soldered, and the main frame, therefore, requires to be made of one piece of wire, and cross-bars are also necessary; but for a considerable time past, all the splints that I have made myself, both for the lower and upper limbs, have been made of this material, and it has proved thoroughly satisfactory, though more difficult to work.

The figures show how the splints may be used in various cases.

Fig. 47 illustrates a method allowing large side windows to be made by splicing additional wires to the original side-bars of the splint, in cases where the latter might require to be cut in order to permit access to a wound. This was done in the case shown in *Fig.* 48, an instance of an extremely severe, open, and highly septic fracture of the lower end of a femur that occurred

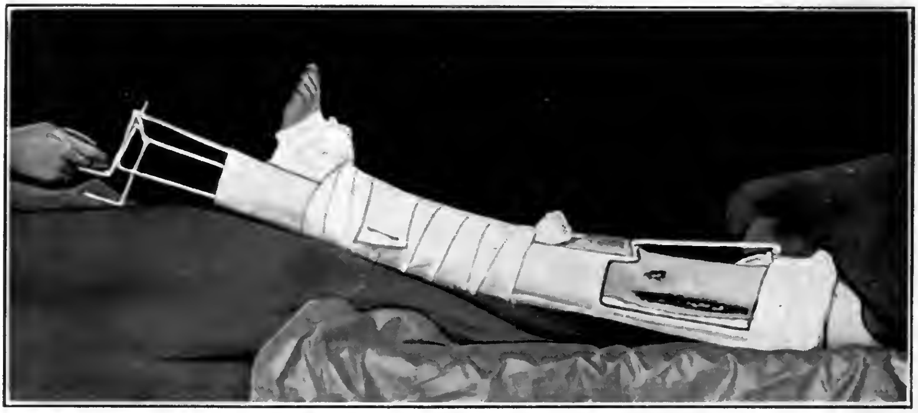

Fig. 48.—Splint of the type shown in *Fig.* 47, applied in an open septic fracture of the lower end of the femur.

in civilian practice, in which a wound down to the bone was produced on each side of the thigh at the time of the original injury. These were excised freely, and through a new incision at the postero-lateral aspect of the thigh the fragments were plated; all the wounds were left open, and the necessary dressings applied through the windows.

Fig. 46 A shows a splint made for a patient whose left leg and thigh had been run over by a heavy motor lorry. When he was admitted to hospital, the limb was enormously swollen from the middle of the thigh down to the toes, and quite cold. The skin of the limb was yellowish-white in colour. Neither of the tibial pulses could be felt at the ankle. There was a fracture through the head of the tibia. The patient was in a state of extreme shock, and it looked as if at least one of the popliteal vessels must have been ruptured. An incision thirteen inches long was made at the back of the limb into the thigh, popliteal space, and leg, evacuating a large quantity of blood, and exposing the large vessels, neither of which, however, was ruptured.

Two other incisions were made at the sides of the leg, one six inches, the other three inches long, into the subcutaneous tissues, which had been stripped off the fascia here by effused blood. The splint used is shown covered in *Fig.* 49. *Fig.* 50 shows it applied to the limb ; a window cut in it to allow access to the lateral wound is seen, as well as the shaped window for the large posterior wound. The patient wore this splint for nine weeks continuously,

FIG. 49.—Skeleton splint illustrated in *Fig.* 46 A, shown covered.

and during this time the wounds were dressed easily, with the minimum of disturbance to the patient ; good union resulted, although at first it was extremely uncertain whether the limb could be saved.

I have employed similar splints for many men sent on from the front with comminuted and septic fractures of the femur, and they have acted satisfactorily in every case. Extension of the fractured bone is well maintained.

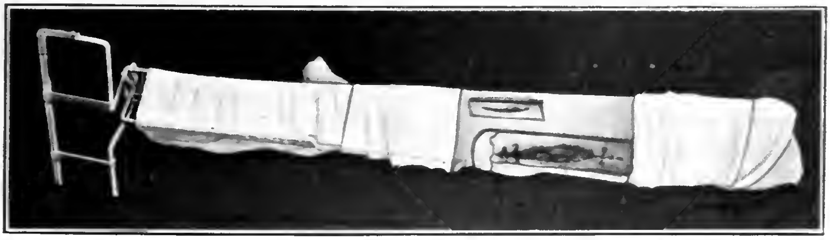

FIG. 50.—The splint shown in *Fig.* 49 applied in an injury of the thigh and leg ; an additional window has been cut in it to give access to the lateral wound.

The patients, from the time of the application of the splints, become so confident regarding the fixation of the fracture, that they are able to move themselves in bed easily, which means they obtain relief from pain ; whereas with the splints in which they were sent on from the front, they could scarcely permit themselves to be touched. These splints do admirably also for open fractures of the leg bones.

In *Fig.* 46 B I show an angled and telescoping wire splint that is of use in certain fractures of the lower limb; it is modelled after a splint, designed for closed fractures, which I described in my book *Fractures and their Treatment*, pp. 172 and 198. It is made with a long, fixed, unaltering leg piece; but the length of the thigh piece, which is the important segment, can be varied by three inches. *Fig.* 51 shows the same splint after it had been covered and applied in the case of an aged female patient with a rather unusual fracture of the shaft of the left femur. She had a long spiral fracture at the upper end, with great displacement of the fragments, as well as a comminuted fracture at the lower end of the shaft. She was treated by placing the limb in this splint, with a heavy extension (not shown in *Fig.* 51) applied in the axis of the flexed thigh, and, in addition, a light elastic extension on the leg. Excellent reposition of the fragments was obtained, with firm union of the bone. This type of splint is made in tinned iron wire, as soldering is necessary, and this cannot be done with the galvanized wire.

In *Fig.* 52 A I show a splint with a long open space at the back, which

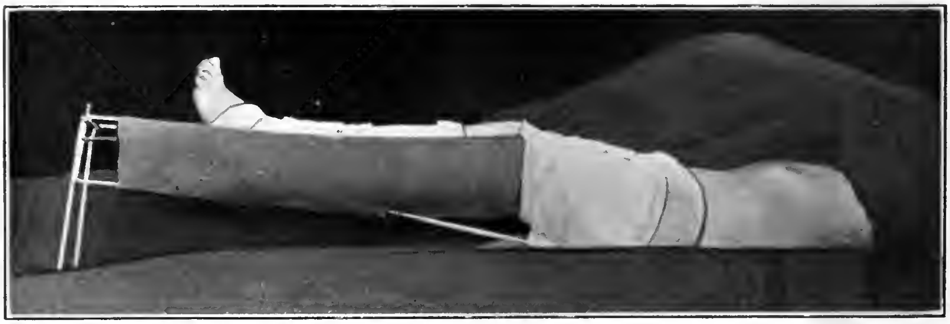

Fig. 51.—Skeleton splint shown in *Fig.* 46B, covered, and applied in a fracture of the shaft of the left femur.

may perhaps be of use in cases where continuous irrigation of a wound is required. A dam of waterproof material should be placed above the level of the wound, in order to check the upward flow of the irrigating fluid.

Measurements Required for the Splints.—It is important that the splints shall fit as accurately as possible, and the measurements I use are:—

1. From the perineum to the sole of the foot.
2. From the tip of the great trochanter to the sole of the foot.
3. From the gluteal fold, in the centre of the thigh, to the sole of the foot.
4. The oblique circumference of the thigh at the great trochanter.
5. The circumference of the limb at the knee, calf, and ankle.

The depth of the splint should equal the diameter of the limb—one-third of the circumference—so that the limb lies deeply in the trough formed by the splint for its entire length. The splint should be longer than the limb; its actual length will be determined by the length of the bed available for the patient. If the splint can be at least one foot longer than the limb it

is an advantage, as the extension, which I carry out by means of elastic tubing or cord, is more easily graded if the fixed point is some distance from the limb than if it is close up to the sole of the foot.

All the splints of this type for the lower limb require a back-bone, composed of a double wire, which can be opened out to make windows when required, as indicated in *Figs.* 46 and 49; its termination forms a convenient point to which to fix the rubber extension cords, which, when attached here, tend to brace up the whole splint and make it rather more rigid.

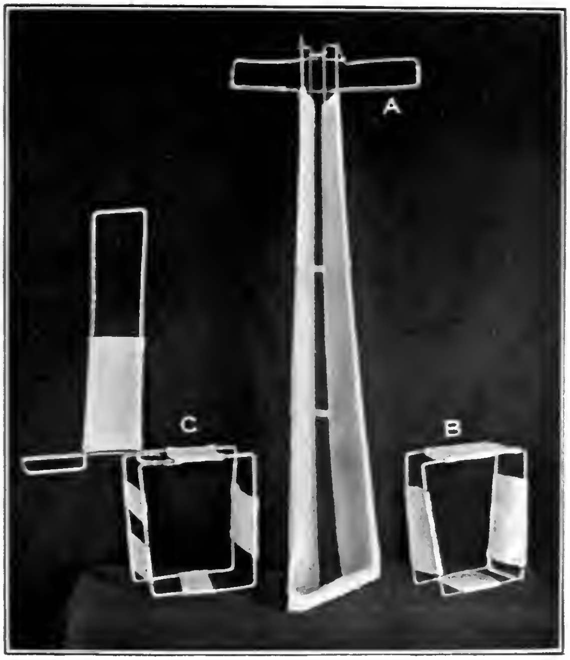

FIG. 52.—A. Splint for the lower limb with a long open space at back, for use in continuous irrigation treatment. B. Simple quadrilateral splint for injuries of the upper limb. C. Quadrilateral splint with forearm piece attached, made for the case shown in *Fig.* 56, where it is seen applied.

It has been found better for the foot-piece of the splint to turn backwards, as shown in *Figs.* 52 A and 46 B, instead of forwards, as at first made; it thus takes up less space in the bed, and is much steadier. The foot-piece may be made up any height, according to the degree of flexion of the femur that is desired, and is steadied by sand-bags when the splint is in use.

The body of the splint is made of two layers of lint (or flannel); the inner one, next the limb, should be looser than the outer, so that when the resin composition is poured on, the two layers shall come into close contact with, and adhere to, one another to form one piece, without any air spaces forming between them. Flannel shrinks more than lint, and this must of course be allowed for.

The ring is padded to the thickness of about an inch, then covered with jaconet, on the top of which a single layer of lint is placed. In this way a soft ring is obtained, as the layer of jaconet prevents the whole thickness of the padding absorbing the composition. Any irregularities on the surface of the ring are smoothed off with a hot iron or knife. The resin composition ought not to be too hot, because then it tends to run straight through the lint, rather than spread out in its substance.

SPLINTS FOR THE UPPER EXTREMITY.

For fractures of the upper limb I employ a wire splint having a quadrilateral shape; but instead of making it in the form of a trough, like the lower-limb splint, I find it better to make the supports, both for the upper arm and for the forearm, almost flat, rather in the form of a shelf, because the quadrilateral shape of the splint, as well as the method of attaching it firmly both to the trunk and limb, allow no chance for the latter to slip from position; more especially is this so when one employs extension. In conse-

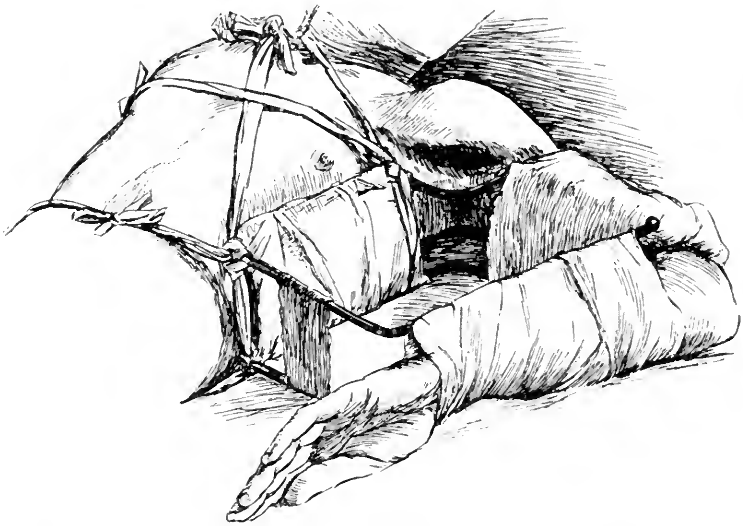

FIG. 53.—Large wound of the anterior wall of the axilla, with extensive destruction of the pectoralis muscle. The hand and forearm are in a position of pronation.

quence, about two-thirds of the circumference of the limb are freely exposed for dressing any wound that may be present on this surface, and if there be a wound on the remaining third of the limb which is in contact with the splint, a window can be cut in the support to give access to it (see *Fig.* 61); or, in certain cases, the support can be done away with completely, as the extension of the limb, and the bandages round it which are required to keep the dressings in position, will hold the part sufficiently steady.

My primary splint for the upper limb is shown in *Fig.* 52 B. I have found this simple quadrilateral of great service in the treatment of a large number

of cases of extensive gunshot injury to the soft parts of the axillary walls, as well as to those over the scapular region, even where there was no bone involvement; because in these cases it is important to keep the muscles concerned in the movements of the shoulder-joint, and which may be themselves involved in the wound, at rest, and in such a position that when healing is completed, the power of abduction of the arm from the trunk will not be interfered with, as is certain to be the case if the arm be maintained at the side. As the abrupt turn of the splint, in its typical form (*Fig.* 52 B), may in some instances extend directly over a wound of one or other of the axillary walls,

FIG. 54.—Gunshot fracture of the humerus, with wide separation of fragments of the bone.

FIG. 55.—The same humerus as that shown in *Fig.* 54 after treatment in the abducted position with a quadrilateral splint.

it will sometimes be found necessary to modify the shape of the splint in order to obtain free access to the wound. In the case of an injury of either wall, the angle of the splint may be made concave opposite the wound, as in *Fig.* 53, or the upper posterior angle of the splint may be replaced by a circle round the wound, as shown in *Fig.* 57.

For cases of open fracture of the humerus, extension is obtained by adding to the primary splint a suitable outrigger of wire, as is shown in *Figs.* 57 and 59. The extension is obtained either by adhesive plaster attached to the limb, or by attaching the rubber cords to pins driven through the

condyles of the humerus (*Fig.* 59). Some of the men suffering from fractures of the humerus do not appear to be able to put up with any extension of the limb at all; in such cases I have found the primary quadrilateral splint alone is still useful; it has quite an efficient steadying effect upon the fragments of bone, provided careful bandaging of the upper arm and of the forearm to their respective supporting sides be carried out. The mere position of abduction in itself is, so far as one can judge from x-ray examinations, sufficient to give a fair re-adjustment and coaptation of the fragments (*Figs.* 54 and 55).

A point to bear in mind in dealing with extensively comminuted fractures of the humerus, such as so often result from gunshot wounds, is that movement of the distal main segment of the shaft, especially rotation, may—in consequence of the associated damage to muscle so often present—altogether fail to influence the position into which the proximal main fragment is thrown

Fig. 56.—Gunshot fracture of the humerus treated with the splint shown in *Fig.* 52 C, to maintain complete abduction along with external rotation of the humerus, and at the same time to keep the limb extended. The posterior wound was free of the splint and accessible for the dressings.

by the unopposed action of muscles attached to it. In such cases, correct adjustment of the main fragments—and in these septic fractures the comminuted pieces must be left to themselves—can only be obtained by placing the distal fragment of the bone in the attitude which corresponds with that of the proximal one. Thus, in *Fig.* 56 the limb is shown abducted to a right angle, and at the same time rotated out at the shoulder so far that the forearm lies parallel with the trunk; for it was found, in the case of this patient, that this attitude gave the best reposition of the main fragments of the bone. The skeleton splint employed in this particular case is shown in *Fig.* 52 C. Here the forearm piece is made parallel to the trunk-piece; but the angle at which the forearm support is set with regard to the rest of the splint can easily be varied, so as to adapt the lower humerus fragment to the degree of rotation that will bring it into the best coaptation with the upper, uncontrollable, main fragment, as shown by x-ray screening and examination under anæsthesia.

In dealing with fractures of the upper extremity of the humerus, it cannot be too strongly insisted upon that the upper arm and the forearm must be adjusted at the correct angle both to one another and to the trunk; so that if ankylosis of the shoulder-joint—not an uncommon sequel in septic cases—is the best result that is to be anticipated, the arm shall ultimately be as useful as possible. The same remark applies to any fractures that may be complicated by a septic arthritis of the shoulder-joint.

This leads me to write of what I call the 'pitch' of the splint. In a large number of cases, perhaps the majority, it seems to me best to maintain the upper arm in the position of abduction at right angles during the process of healing; but this attitude will not always give the best coaptation of the fragments, so that it is necessary to decide at the commencement of treatment whether the arm shall be completely abducted or not. The position which gives the best reposition of the fragments must be chosen to start from. If this happens to be one that is less than a right angle, it may be possible to improve it as time goes on. For example, in cases where a wound involves either of the axillary walls, inflammatory exudation into the tissues might prevent—for the time, at any rate, and possibly permanently — complete abduction of the upper fragment; so that if one attempts to abduct completely the upper arm in these circumstances, it will result in angulation of the fragments at the site of fracture; if this be shown to be the case on screening, the arm must be abducted at such an angle that the fragments come into alinement. In *Fig. 57* I show how the 'pitch' of the humerus side of the splint can be varied by arching the lowest, free side of the quadrilateral; by doing this, one of course approximates the forearm and trunk pieces of the splint at their lower ends, and so the angle which the support for the upper arm makes with the trunk piece can be altered to meet the posture which best brings the fragments into alinement. As improvement in the state of the soft parts takes place with stretching, absorption, etc., it may become possible

FIG. 57.—Cavernous exit wound after a perforating gunshot injury to the left arm. A comminuted fracture of the upper third of the humerus was produced, and the muscles of the posterior wall of the axilla were extensively destroyed. Free access is given for dressing the posterior wound. The anterior wound was free of the splint. The fracture was treated by extension together with 'position,' the humerus side of the splint being 'angled' to the required degree by arching the lower side of the splint.

to obtain more and more abduction of the proximal fragment of the bone, by gradually straightening the lower side of the splint and thus elevating the humerus support again.

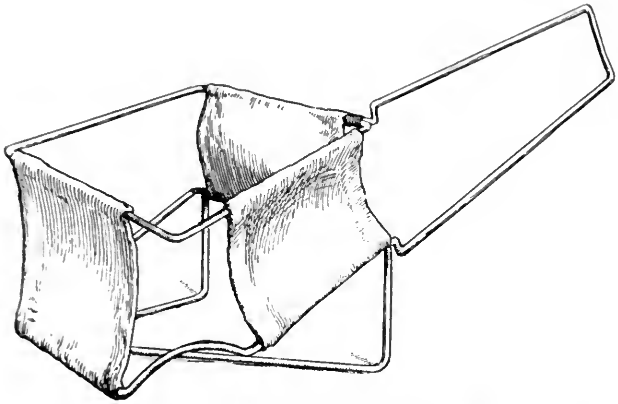

Fig. 58.—Skewed wire splint, with resin-impregnated supports for the limb, for maintaining abduction at the shoulder, along with flexion, in cases of fracture about the neck of the humerus. Extension of the humerus is provided for by splicing an outrigger to the main splint, the posterior wire of which is made concave at the axilla to allow access to a septic wound in the posterior axillary wall.

Another point in connection with the position of the limb, which generally concerns the fractures about the neck of the bone, is that it may be advantageous to keep the arm advanced, more or less, from the frontal plane, i.e., to keep it flexed at the shoulder-joint, while still maintaining it fully abducted. This can be allowed for in fashioning the skeleton wire splint, which for this purpose must be made skewed, so that the body-piece, which must lie parallel with the trunk of the patient, has the other three sides of the splint set to it at the angle which wil give the necessary flexion at the shoulder-joint. It necessitates, however, a firm support below the forearm piece, the patient being in bed; without it, the posterior wire which forms the posterior margin of the trunk piece, in consequence of the rotation caused by the weight of the arm and splint together, would be apt to press the skin unduly, and might cause a pressure sore; but with a support such as is shown in *Fig.* 58 it is quite efficient. The further forward the arm is carried for this purpose, the more constrained does the attitude of supination become, and in such cases it is decidedly easier for the patient to have the forearm in a state of pronation (see *Fig.* 53).

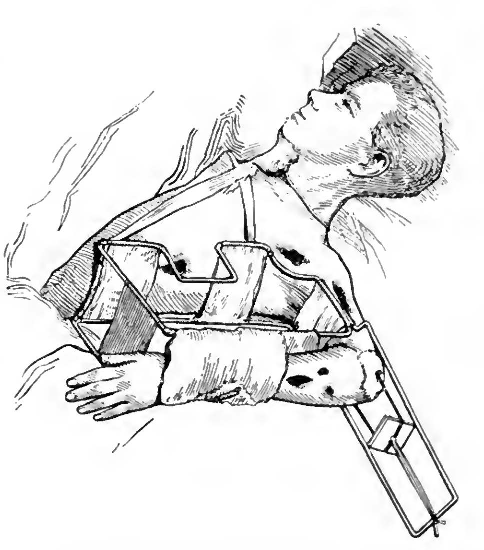

Fig. 59.—Quadrilateral splint, modified for application to a patient with a compound fracture of the humerus and additional wounds of the chest wall, axilla, and forearm, and with outrigger attached for obtaining extension. The extension is applied in this case by means of a pin driven through the condyles of the humerus.

The great advantage of employing wire in these splints is that any adaptation required for wounds, etc., in the shape of the splint, can be effected during their construction, and thus one is enabled to deal with practically any wounds that may be present, as well as with fractures. *Fig.* 59 shows a splint which I made for a patient who was suffering from (1) a septic fracture of the left humerus caused by a perforating gunshot wound (only one of the arm wounds is seen, the other being at the back of the limb); (2) a large wound involving the pectoral muscle in the anterior axillary wall; (3) another wound on the thoracic wall leading to fractures of the 7th and 8th left ribs; and (4) three wounds on the forearm. All of the wounds were highly septic. The patient was extremely ill from sepsis when admitted, and unable to sleep owing to the extreme pain in the limb, which was only supported on a wooden splint that required to be removed every time a dressing was necessary. My splint, along with the extension applied to the humerus, gave immediate relief, in consequence of the support it gave to the fracture; and all the wounds were made easily accessible for the necessary dressings.

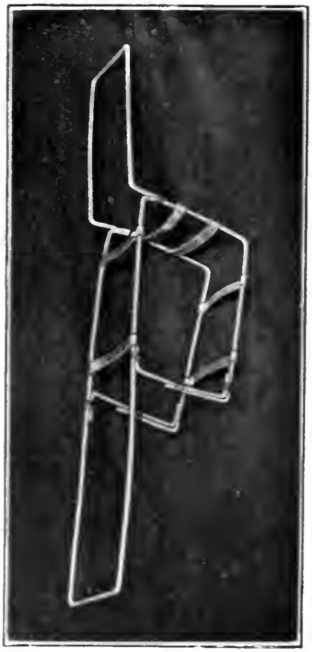

Fig. 60.—Skeleton splint for open fractures of the forearm bones. It is shown in application in *Fig.* 61.

For open fractures of the forearm bones I use a splint such as is shown in *Fig.* 60; *Fig.* 61 shows one of these splints in use. Extension is easily obtained, and the freest access can be given to any wounds that require dressing. When applied as shown in *Fig.* 61, with the palm of the hand lying against the splint, the forearm is in the attitude of complete supination (radio-ulnar). This position is of importance for many fractures of the forearm, however produced, whether in military or civil practice, but especially so in septic, comminuted, gunshot fractures; for, in this position, the shafts of the bone are kept as widely apart as is possible. Where there is considerable smashing of the forearm bones, I find it is easier to maintain supination, and more comfortable for the patient, if the composition support for the forearm is brought down far enough for the palm of the hand to rest upon. It is, however, just as easy to obtain a position of pronation (see *Fig.* 53), should it be found necessary and advantageous. I notice that where the forearm is left free, i.e., is not extended, the men wearing these quadrilateral splints frequently lie with the hand in the attitude depicted in *Fig.* 53, in complete pronation, as being an easy and comfortable one.

In fractures of the humerus where union is sufficiently far advanced, these splints, while still supporting the damaged bone, allow of free active movement being carried out at the elbow-joint, a point of very considerable importance in treatment.

Up to the present time I have not had any opportunity of testing the splint in a septic fracture of both the humerus and the bones of the forearm; but in a case of this kind, the extension could quite easily be applied to both segments of the limb by adding, for example, a humerus extension outrigger to the splint illustrated in *Fig.* 61.

Fig. 62 represents a telescoping and adjustable splint which Messrs. Rowat & Co. have made for me, and which is distinctly useful. It expands in each of its four sides from seven to ten inches, so that it will fit individuals with limbs which differ considerably in size; and it can also be angled as required to fit it to the displacement of the fragments of the humerus shaft; while its joints can be locked so firmly that the splint will remain perfectly rigid at any angle (*Fig.* 63). These appliances are especially useful as temporary aids in fixing a fracture until a lighter wire splint can be turned up to

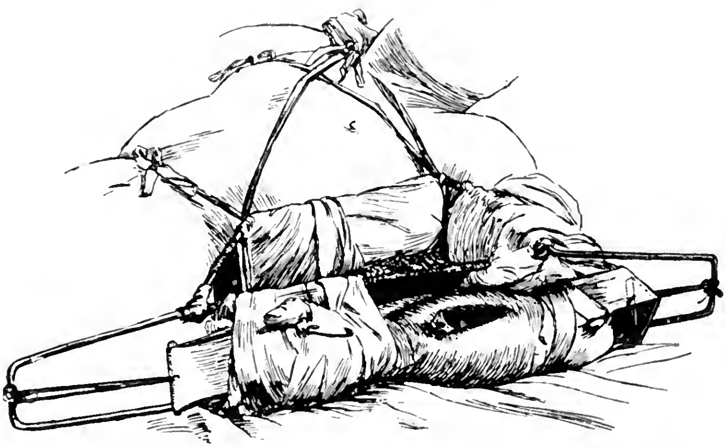

FIG. 61.—Perforating gunshot wound of the forearm, with extensive comminution of the radius. A window has been cut in the support for the forearm, to give access to the wound in the anterior aspect of the limb. The hand and forearm are in complete supination.

fit the individual patient. It is quite easy to add extension outriggers for the humerus or the forearm bones, either by wiring them to the main splint, or by having slots soldered on the latter into which the outriggers can be fitted. It is rather heavier than the ordinary simple wire splint, being made of thicker wire; it weighs, with lint and resin supports, $2\frac{3}{4}$ lb., as against the $1\frac{3}{4}$ lb. of the splint shown in *Fig.* 52 B, and this is almost its only disadvantage. It has been worn by men who had previously carried one of the lighter wire quadrilateral splints for several weeks, and they have assured me that it is perfectly comfortable and not at all too heavy.

It will be observed that nearly all the illustrations of the fractures of the upper limb show the splint applied to patients lying in bed. For my part, I believe patients with open fractures of the humerus are best treated lying down. As a matter of fact, when men suffering from gunshot fractures come to us, they are nearly all so seriously ill from sepsis that they cannot be in any other attitude. The splints may be a little awkward, but are no

bar to patients who wish to be up and about and who still require support for their fracture ; if the man's general condition permits it, he quickly learns to steer his way fairly well even with one of these splints attached.

The various illustrations give a fairly accurate idea as to the measurements that may be required, but these vary so much in different cases that one cannot lay down definite rules.

I would only add, for the benefit of anyone who may desire to make the splints himself, that the measurements ought to be correctly made, and the calculated length of wire should allow for a certain amount over and above ; and that, before making any bend in the wire during the construction of the splint, one should be quite certain of the correct plane in which it ought to go ! In making arm splints, it is well to begin them at the cross-bar forming the lower extremity of the body piece (see *Fig.* 61), which may generally be taken as being about the centre of the length of wire required.

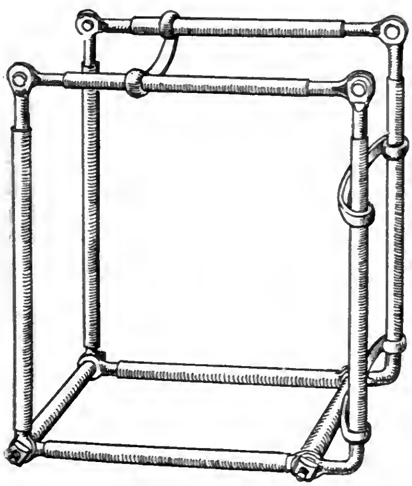

Fig. 62.—Telescoping splint, set at a right angle as for the right upper limb. Each side as shown measures 7 inches in length.

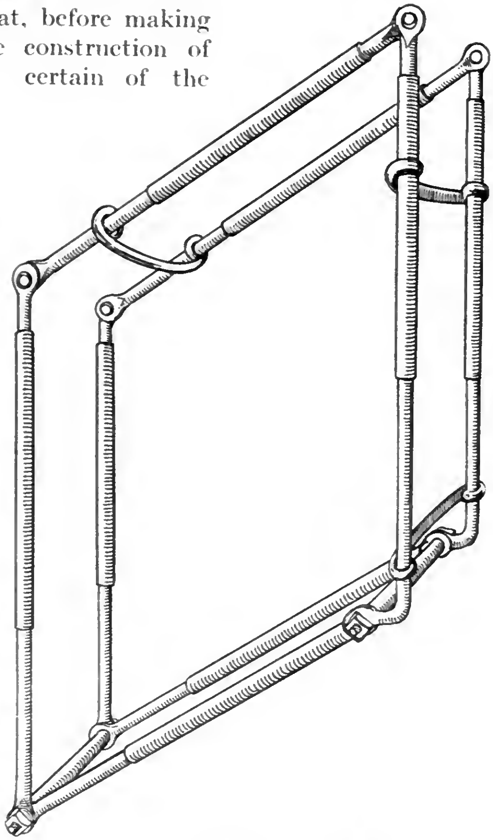

Fig. 63.—The same splint as shown in *Fig.* 62, set at an angle and locked by the locking nuts. Each side is here expanded to 10 inches.

A large number of the splints I have made up myself, but I desire to acknowledge the very great assistance received from Dr. T. Jackson, who was my house surgeon for nearly twelve months after the gunshot fractures came under observation. My thanks are also specially due to Miss J. B. Craig, the excellent sister of my wards, whose help in this, as in most of my work, has been invaluable.

THE CARREL TREATMENT OF WOUNDS.

By Colonel G. BARLING, A.M.S.

The essence of this treatment consists in the frequent instillation into the wound of a solution of sodium hypochlorite free from caustic soda.

The purpose is to destroy infection by constantly exposing it to the antiseptic, thus lessening the risks of septic absorption, shortening the process of healing, and enabling many wounds—whether simple, or associated with fracture or joint opening—to be closed by secondary suture.

It will be well first to say something as to the antiseptic now known as Dakin's fluid. With this article will be found a complete description of the preparation of the fluid devised by Dakin in collaboration with Dr. Carrel (for the translation I am indebted to Major Irwin, R.A.M.C.) Their aim has been to produce a solution containing not less than 0·45 per cent, nor more than 0·5 per cent, of hypochlorite of soda, the first being regarded as inefficient, the second as irritating. The presence of caustic soda is harmful because of the irritation it produces in the surrounding skin. To determine the presence or absence of this alkalinity, *powdered* phenolphthaleine is added to some of the solution; if caustic soda is present, the solution turns an intense red; whilst if it is properly compounded, there is no change in the coloration. Like all the hypochlorite solutions, Dakin's fluid is unstable, and must be protected from light, the best method being to use large receivers made of black glass, surrounded by wicker cases.

The antiseptic is carried into the wounded tissues by means of ordinary small rubber tubes, varying in size from about a No. 5 to a No. 10 india-rubber catheter. These tubes are closed at the end by a ligature, whilst they are perforated at short intervals by tiny holes made with a dental punch, the purpose being to retain some of the fluid in the tube, whence it will escape slowly into the wound; there is no intention to irrigate in the ordinary sense of the term. The minute lateral openings in the tubes extend over one, two, or more inches of their length, corresponding to the depth of the wound, or to its length if they are laid flat on the surface; if the openings cover an unsuitable length of the tube the fluid escapes outside the wound on to the skin, which is not desired. *Figs.* 64–67 show the distributing apparatus arranged for one, two, three, and four tubes respectively. If the wound is superficial, the terminal two or three inches of the tube may be surrounded with a thin layer of towelling, to help keep it in place. Again, if there is a cavity in the bone, a tube may be used the end of which is left open, and no lateral openings are made. The number of tubes used in a wound may vary from one up to eight or even ten. For instance, in treating a compound fracture into the ankle-joint, a group of about four tubes is usually sufficient; whereas with similar conditions at the knee-joint, when there is extensive injury to the bone, at

least about twice as many would be required when the early septic condition is attacked.

The tubes must be of such length as to allow of their being brought out through the dressing without bending or kinking. If one tube only is used, the antiseptic is most easily instilled by means of a small syringe such as that shown in *Fig.* 68, or the Koch syringe, but this must not be done forcibly; the same instrument may be used if there are multiple tubes, but economy of time is promoted by joining the tubes in groups to glass pieces with two, three, or four limbs, these in turn being connected with a single tube leading to a small reservoir (*Fig.* 69) containing the Dakin fluid, the supply to the wound being controlled by a small pinch-cock (*Fig.* 70) in the tube between the reservoir and the glass junction. The glass reservoir is suspended near the head of the bed, at a convenient height, and out of the way of injury.

FIG. 64.

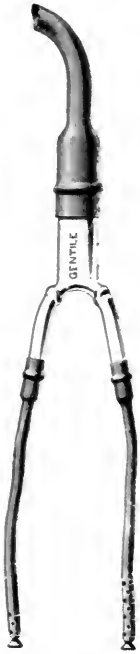

FIG. 65.

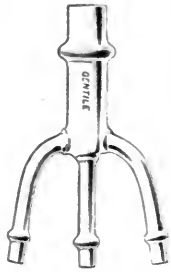

FIG. 66.

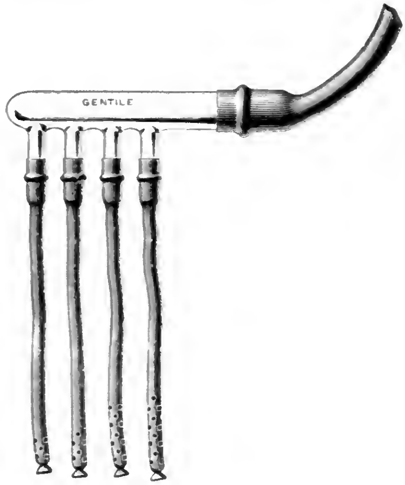

FIG. 67.

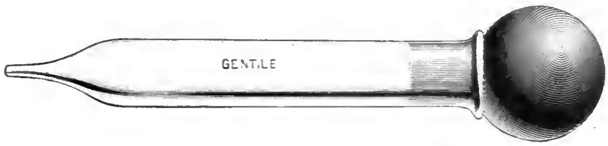

FIG. 68.—Carrel's syringe.

The tubes must be watched to determine whether the antiseptic flows evenly to all the branches so as to secure a general distribution to the wound. The amount applied every two hours depends upon the area of the wounded surface, but usually from ten up to thirty cubic centimetres are admitted at each instillation, according to the number of tubes and the extent of the wound.

The dressing materials used consist of small pieces of plain gauze about the size of the hand, and of pieces of Gamgee tissue or some similar material cut into portions of suitable size for the individual wound to be treated. In different clinics the details vary somewhat, and later on I shall briefly refer to these; but I may mention here that there is no packing of wounds with gauze in the sense in which this term is used in connection with salt packing. Absorbent cotton-wool, unenclosed between layers of gauze is not a suitable material for this method; it is difficult to handle, sticks on and around the wounded part and to the dresser's gloves, and takes up more time than, for instance, Gamgee tissue; this last point is a matter of some importance when a number of dressings have to be changed.

My first opportunity of seeing the Carrel method was at a hospital where Dr. Carrel has a clinic of somewhat less than 100 beds. Subsequently I had the advantage of also seeing Professor Tuffier's wards, and in his absence his cases were demonstrated by his assistant, Mdlle. Dr. Hartmann. At the same period I also attended the American ambulance in Paris under the direction of Dr. Hutchinson, and the Hôpital Buffon directed by Dr. Chutro. At each place I was most kindly received, and everyone was most willing to show me everything at their disposal, and to give me information on all points. I would like here to express my grateful thanks for the courtesy shown.

At Carrel's hospital there is the most complete demonstration not only of the clinical treatment, but also of its complement the bacteriological examination of the wounds, to which I refer later. An admirable illustration is also given of the clinical progress of wounds by means of the lantern. Photographs in colour are taken at various stages of the wound, the healing of which at different periods can thus be followed; and if the patient is still in hospital, a still later stage can be observed by the visitor.

Fig. 69.—Complete apparatus for massive intermittent irrigation.

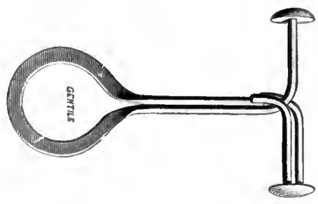
Fig. 70.—Mohr's pinch-cock.

The bacteriological method is quite simple. By means of a sterilized platinum wire a smear is taken from one or more parts of the wound, spread on a slide, and suitably stained. If it is a recent wound, the first examination usually reveals a large number of organisms of various kinds in each field of the microscope. About every two days this examination is repeated, and it may be that in the early stages the number of organisms actually increases; for instance, there may be thirty per field at the first examination, and at the

second sixty or infinitely more; but gradually the number of organisms per field drops, and at the end of ten days perhaps only five per field are found; a week later perhaps only one organism is seen in a field, to be followed by a further drop to one organism in four or five fields. If the clinical condition of the wound is in accord with the favourable bacteriological report, the time has arrived when the wound may be closed by suture. When this is possible, in cases of extensive gaps in the soft tissues, or in the presence of a compound fracture of an open joint, the advantages are great. Not only is the patient saved from the risk of secondary infections of his wound, but his stay in hospital may be materially shortened. The curve in the bacterial chart is not always in the direction of improvement; at times there may be a considerable jump in the record of bacteria found—sometimes without recognizable cause, at other times due to the removal of, say, a fragment of necrosed bone. The improving curve generally returns in a short time, and the normal fall to zero follows. Before closure of a wound, it is desirable to investigate more than one part of it, as the flora vary in different parts of the same wound. It is specially desirable to investigate secretions from any deep part or pocket: if the bacteria are fairly numerous on such an investigation, however satisfactory the remainder of the wound may be, closure should be deferred until the deep part shows better bacteriological results.

The technic of the dressings at Carrel's hospital is carried out with the most scrupulous care. The wounds are dressed every day, a course which is not followed everywhere. The surgeon is suitably clothed for his work, and wears gloves; he does not touch the wound even with his gloved hands, but removes the soiled dressings with two pairs of forceps, and uses the same instruments to readjust or replace the tubes if necessary, to apply pieces of gauze moist with Dakin's fluid, and over this to apply a layer of dry gauze. The skin for some inches around the edge of the wound is thoroughly cleaned with a fluid neutral soap, forceps holding a small swab being used for this purpose, as also to remove any excess of discharge from the surface of the wound itself. The outer pads of the special tissue are then brought together, and clipped with the forceps which have been used by the surgeon, who passes on to the next case, leaving a nurse to make a more permanent fastening of the dressing. To sum up, the dressing is carried out with as much care as though it were an operation on aseptic lines.

What are the results obtained by Dr. Carrel? The cases I had the opportunity of observing were *nearly all old cases* from other institutions, which I was assured arrived at Carrel's hospital after long suppuration—for weeks or months—and still suppurating. The records confirmed this. Many of these wounds were associated with considerable lesions of bone or joint. When the wounds were exposed by the removal of the dressing, I found that they were granulating beautifully, there was a complete absence of pus, and the only discharge was a semi-coagulated fluid looking like clear lymph or very thin glue. After one's experience of the prolonged suppurations in so many of the cases arising in the war, I felt that I was in the presence of successful wound treatment such as I had not seen approached by any other method.

The question arises: Is it possible for us to attain similar results in

English hospitals? In answering this, one has to bear in mind that Carrel's clinic is really an experimental hospital, provided with elaborate assistance in the way of laboratory, and medical and nursing staffs. The work is carried out by those who are through long experience intimately versed in the details—a really important matter—and as keenly interested in the success of the work as is their chief. The demands made by our hospitals upon surgeons and nurses, and the limited supply, render it impossible for us to have anything approaching the personnel of this Carrel hospital. In a busy time, such as occurred last summer, a great deal of dressing is of necessity left to the nursing staff, with supervision of the graver wounds by the surgeon. Does this render Carrel treatment in our hospitals an unsuitable method? Again, can we emulate in recent wounds the striking success attained in those of much older date? The answer to these two important questions is partly supplied by what I saw at some of the other hospitals, and partly by the experience I have so far had in the hospitals at Rouen.

At Chutro's hospital, the nursing staff is not so numerous as at Carrel's, though still more numerous than ours; but Chutro has so modified the method of dressing as to curtail the demands on the surgical and nursing staff to a very considerable degree. For instance, the dressing is not changed every day; the routine time is every second day, and in cases approaching their termination a longer period may be allowed to elapse. Again, no cleansing by soap is made of the skin around the wound; thus, in each dressing a few minutes are saved. It must also be remembered that in his hospital of some 300 beds, not a single splint is used to fix injured limbs, whether of the upper or of the lower extremity, whether associated with fractured bone or infected joint. In the lower extremity the limb is fixed by Chutro's extension-stirrup, passed through the tissues immediately in front of the tendo Achillis and above the upper margin of the os calcis; counter-extension is secured through the weight of the patient's body, by elevating the foot of the bed. The part is also steadied a good deal by the thick outer dressing devised by Dr. Chutro, and by a thin metal tray underneath the limb, which also prevents leaking of the antiseptic into the bed. The patient is kept very level by a strong fracture-board on which is superimposed a thick and very rigid but comfortable mattress. Whether Chutro's method of controlling the limb without splints is a good one or not, it undoubtedly facilitates dressing, and I saw no untoward results from discarding splints.

Chutro's outer dressing has much to recommend it. It is of large area: that for application to a high compound fracture of the femur would be split at its upper margin posteriorly and carried well over the buttock and the iliac region, and downwards to the knee or below. It is secured in position by ties of tape, no bandage being used. The dressing material is a very thick layer of good non-absorbent cotton-wool, with a thin layer of absorbent wool superimposed, the whole being enclosed between two layers of gauze or muslin. When the dressing is re-applied, the ties are undone, the outer covering falls open, the soiled gauze is removed, and the tubes are readjusted; but no cleaning of the skin around is attempted. Fresh moist, and then dry, gauze is applied, as at Carrel's hospital, and the covering is closed and tied again; or if it is

considered necessary, a fresh covering is used, a change required perhaps every time the wound is dressed, every fourth or every sixth day.

Dr. Chutro also reduces the bacteriological examination to a minimum. Wound films are not examined as a routine, but only in those cases which have reached the stage at which there is a prospect of being able to employ secondary suture; then the investigation is made over a period of several days. This is of course the really important time for the determination of the bacterial content of the wound, and in British hospitals we may well take a hint from Dr. Chutro, or the pathologists at the various hospitals will be overburdened.

In the late cases which formed the bulk of those seen at Carrel's clinic, little appeared to have been done in the way of opening up the wounds afresh, unless it was evident that some part of the wound was difficult of access or was pooling secretion; in such circumstances some enlargement of the existing wound was resorted to.

In the case of recent wounds a different course is required, and at Rouen we are working for the present on the lines I now mention. The wound is opened up freely so as to give ready access to all parts, and the damaged and badly infected tissues are removed as freely as the occasion requires and the position of the injury allows. If the injury is a fracture of the skull or a wound into a knee-joint such as we have been in the habit here of closing by immediate suture, that course would be adopted. If, on the other hand, the knee is too badly infected, or damage to the tissues will not allow of closure, Carrel's treatment would be begun at once, as it would be also in the case of compound fractures, or such wounds of the soft tissues without fracture as do not lend themselves safely to immediate suture. Counter-openings for drainage are not made, as they have the disadvantage of allowing the instilled fluid to escape almost as soon as it is introduced; but, on the other hand, much care is taken to remove all gross foreign material, and also all badly-injured tissue, not only in the soft parts, but also in the end of a bone entering into a joint. In the case, for instance, of a wound of one of the femoral condyles, a gouge, or a chisel and mallet, is used to get a clean surface of bone; but if there is a split into the femur, partly separating the whole condyle, the latter is not removed bodily. In the case of a compound fracture in the shaft of a long bone, the decision as to how much bone should be removed is not an easy one. If fragments are very freely removed it is easier to overcome the infection, and healing with or without secondary suture is secured at an earlier date; but such free removals are apt to be followed by failure of bony union. Several such failures of union have come under my observation. The general routine followed is to remove all entirely loose fragments, and to leave those which have some prospect of wholly or partly surviving. The wound having thus been thoroughly prepared, the instillation tubes are introduced in such numbers as will secure a thorough exposure to the influence of the hypochlorite solution, and the parts are supported by suitable splints. After amputation, Carrel's method may also be adopted, and in cases where there is no spreading infection from anaerobic organisms, flaps are generally made and loosely closed with sutures, and tubes are introduced freely, some being placed well into the larger areas of loose connective tissues between the muscles, etc.

The dressings are usually changed every day, unless an anæsthetic is required, when they are left two or three days. If the skin becomes sore and irritable around the wound, it is smeared with vaseline, which makes a good protection, or strips of gauze coated with vaseline may be applied. Skin irritation may be due to caustic alkali in the Dakin solution, and the solution should be tested to determine this.

It is too early yet to speak freely of the results obtained at the Rouen hospitals. The surgeons have so far had but a limited experience of Carrel's method, and the nursing staff are in the same position. There can be little doubt that familiarity with the details insisted on so emphatically at the Carrel clinic, is a very important element in obtaining the highest degree of success. Then, again, the wounds we have to treat at Rouen are much more extensive and severe than most of those seen at the clinics I visited ; quite a number of our patients suffer from multiple wounds in different parts of the body, which again adds to the difficulties of treatment by both surgeons and nurses. It must also be remembered that the cases come to us in the full flush of their septicity, either to be treated primarily by Carrel's method here, or having a day or two previously been so treated at the casualty clearing stations. It is impossible to compare the course of such cases with that of the cases I saw at Carrel's hospital. It is most difficult to appraise accurately either the dose of sepsis the patient has received or his individual resistance to it ; this should make us cautious in drawing wide conclusions from a limited number of happy results. With these reservations, I may now say that we have attained such a measure of success as I have not seen secured by other methods, and I anticipate that further experience will give still better results. A fair number of cases have been closed by secondary suture, mostly wounds of soft parts only, as we have been feeling our way with caution ; but I anticipate that the future will provide greater opportunity for secondary wound closure.

It will be well for those who propose to adopt Carrel's method of wound treatment not to expect immediate miraculous results, but to remember the long period of plodding endeavour spent by the originator before he achieved his present success, and to remember also our long battle against sepsis during the whole of the present war. To ensure the best results, the surgeon must not only educate himself in the details, but he must take the trouble to train his nursing staff, so that they may have an intelligent understanding of his aims and be prepared with tubes, forceps dressings, etc., to facilitate his work and economize his time.

Those who have come in contact with Dr. Carrel, and who know his work, cannot be otherwise than deeply impressed by his results. In chronic cases, such as I have seen in such large numbers in the military hospitals in England, there seems no reason why we should not emulate the results obtained ; but this can only be done if the surgical and nursing staffs of hospitals will take the trouble to understand the principles on which Carrel's work is based, and will attend diligently to all the details. In other words, there is nothing really difficult or abstruse about it ; it is simply a matter of taking pains. For the majority of the surgical staffs who have no opportunity of visiting Carrel's or other clinics where this method is employed as a routine, an excellent guide

has been written by Carrel and Dehelly. It is entitled, "Le Traitement des Plaies Infectèes," and is published by Masson et Cie, Paris, price 4 francs.

When we attempt to compare results obtained at British base hospitals in France with those at Carrel's clinic—that is, in the recently wounded—we have to bear in mind one radical difference between the two. At Carrel's hospital patients are frequently admitted within a few hours, six to ten, of being wounded. If the wounded tissues are then widely opened, and where necessary excised, and foreign materials removed, there is no gross infection to be combated, it has not had time to establish itself. Under these circumstances instillation of Dakin's fluid may be expected to give early sterility in the wounds. At our base hospitals the conditions are different; most of the patients have been wounded forty-eight hours or more before arrival.

The best results should be obtained at the casualty clearing stations, because there cases are received quite early. When moderate numbers of wounds are coming into these stations, they can be dealt with on the above lines, and transmitted to the bases in ambulance trains where the treatment can be continued.

[*Translation.*]

THE PREPARATION OF DAKIN'S SOLUTION.

(Daufresne's Method.)

Dakin's solution is a solution of hypochlorite of soda intended for surgical use, possessing the following characteristics, established after numerous trials and long experience in its use:—

1. *Complete absence of caustic alkali.* The absolute necessity of using in the treatment of wounds a hypochlorite solution deprived of caustic soda must completely put out of court Javelle waters (commercial), Labarraque liquor, and all solutions prepared by any other process than that about to be described.

2. The concentration of hypochlorite of soda is rigorously restricted to between 0·45 and 0·50 per cent. Below 0·45 per cent hypochlorite the solution is not sufficiently active; above 0·50 per cent it becomes irritant.

Chemical Products necessary for the Preparation.—Three are indispensable for the manufacture of Dakin's solution: chloride of lime, exsiccated carbonate of soda,* and bicarbonate of soda. Of these three products, the last two possess a practically sufficient constancy of composition: but it is not the same with the first, its content of active chlorine (discolouring chlorine) varying between very wide limits, and it is absolutely essential to titrate it before using.

Titration of Chloride of Lime.—To carry out the titration of chloride of lime, it is necessary to procure: A burette of 25 c.c. graduated in tenths of a c.c.: a graduated pipette of 10 c.c.: a decinormal solution of hyposulphite of soda.

This decinormal solution of hyposulphite can be obtained commercially ready-made (Poulenc); or one can prepare it oneself by dissolving 25 grms. of pure crystallized hyposulphite of soda in 1 litre of distilled water, and testing the solution by

* This product can be easily obtained commercially under the name of "Solvay Soda" or "Solvay Carbonate of Soda." If it is impossible to procure it, and only crystallized carbonate (crystals) can be obtained, it will be necessary (on account of the water of crystallization) to use 2·85 times more of the latter salt.

seeing that it discolours an equal volume of a decinormal solution of iodine, the latter obtained by dissolving 1·27 grms. of iodine and 5 grms. of iodide of potassium in 100 c.c. of water.

The material for the operation being ready, prepare a mean sample of the chloride of lime, which may be done either with a probe *ad hoc*, or by lifting from various points in the mass small quantities which should be carefully mixed afterwards.

Weigh 20 grms. of this sample, mix it as perfectly as possible with 1 litre of ordinary water, and leave for several hours, shaking it from time to time. Filter. Measure exactly, by means of the graduated pipette, 10 c.c. of clear liquid; add thereto 20 c.c. of a solution of iodide of potassium (1–10) and 2 c.c. of acetic acid or hydrochloric acid. Let fall, drop by drop, into this mixture a decinormal solution of hyposulphite of soda until discoloration is complete. The number of cubic centimetres of the hyposulphite solution necessary to obtain discoloration, multiplied by 1·775, will give the weight of active chlorine contained in 100 grms. of chloride of lime. This figure being known, refer to the following table, which gives the quantities of chloride of lime, carbonate of soda, and bicarbonate.

Standard of Chloride of Lime	Quantities Required to Prepare 10 Litres of Dakin's Solution containing from 0·45 to 0·50 per cent NaClO		
	Chloride of Lime Grms.	Exs. Carbonate of Soda Grms.	Bicarbonate of Soda Grms.
20	230	115	96
21	220	110	92
22	210	105	88
23	200	100	84
24	192	96	80
25	184	92	76
26	177	89	72
27	170	85	70
28	164	82	68
29	159	80	66
30	154	77	64
31	148	74	62
32	144	72	60
33	140	70	59
34	135	68	57
35	132	66	55
36	128	64	53
37	124	62	52

Example.—If 16·6 c.c. of decinormal solution of hyposulphite are required to obtain discoloration, the titre (standard) of active chlorine in the chloride of lime tested is 16·6 × 1·775 = 29·7 per cent. The quantities to be used in this case to prepare 10 litres of solution will be :—

Chloride of lime	154	grms.
Exsic. carbonate of soda	77	,,
Bicarbonate of soda	64	,,

If there is only crystallized carbonate of soda at hand, it would be necessary to replace the 77 grms. of exsiccated carbonate by 220 grms. of the crystallized salt.

Preparation of Dakin's Solution.—To prepare 10 litres of the solution :—

1. Weigh exactly the quantities of chloride of lime, carbonate of soda, and bicarbonate of soda which have been arrived at in the course of the previous calculation.

2. Introduce into a 12-litre flask the chloride of lime and 5 litres of ordinary water, shake briskly for five minutes, and leave from six to twelve hours, say for one night.

3. At the same time dissolve, cold, in another 5 litres of water, the carbonate and the bicarbonate of soda.

4. Pour out at one operation the solution of salts of soda into the flask containing the mass of chloride of lime; shake briskly for a few moments, and then let it rest to allow the carbonate of lime which has formed to deposit itself. At the end of half an hour syphon off the liquid and filter it through a double paper in order to obtain a perfectly limpid product, which should be kept sheltered from the light. Light, indeed, changes solutions of hypochlorite fairly rapidly, and to preserve their effect it is indispensable to keep them from its action. The best way is to keep the finished liquid in large black glass carboys, encased in wicker.

Titration of Dakin's Solution.—It is well to verify from time to time the standard of the solution. This operation requires the same apparatus and products as those for determining the active chlorine in the chloride of lime.

Measure out 10 c.c. of the solution, and add thereto 20 c.c. of solution of iodide of potassium (1–10) and 2 c.c. of acetic or hydrochloric acid. Let fall, drop by drop, into the mixture, a decinormal solution of hyposulphite of soda until discoloration is complete. The number of cubic centimetres employed, multiplied by 0·03725, will give the weight of hypochlorite of soda contained in 100 c.c. of the solution. The solution is of a correct standard when, in the above operation, 12 to 13 c.c. of decinormal hyposulphite are employed to obtain discoloration :—

$$13 \times 0{\cdot}03725 = 0{\cdot}485 \text{ per cent of } NaClO.$$

Trial of the Alkalinity of Dakin's Solution.—It is easy to differentiate between the solution obtained by this process and the commercial hypochlorites and Labarraque liquid. Pour into a glass about 20 c.c. of the liquid to be tested, and let fall on the surface a few centigrammes of *powdered* phenolphthaleine. Dakin's solution, correctly prepared, gives absolutely no colour, while Javelle water and Labarraque liquor give an intense red colour, which indicates the presence of free caustic soda.

THE TREATMENT OF HÆMORRHAGE CAUSED BY GUNSHOT WOUNDS OF THE FACE AND JAWS.

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and Captain HAROLD BURROWS, R.A.M.C. (T.F.)*

Of the many complications which arise in the treatment of gunshot wounds of the face and jaws, secondary hæmorrhage is one of the most serious, and is a common cause of fatality. This fact has been emphasized by previous writers on war surgery, yet it is usually discussed in a general way, without definite analysis of its nature, frequency, and allied complications.

The following remarks are compiled from the records of 400 cases of gunshot wounds of the face with fracture of the jaws treated in the department of oral surgery at a general hospital where, between the dates of admission and of evacuation, sufficient time is given for comprehensive treatment and observation during the different stages of progress.

Condition of Patients on Admission to Hospital. — Though the maxillæ are the parts most affected, it can hardly be said that the injury is limited to these tissues alone. The missile is apt to cause comminution of many bones of the face, and to lacerate the eye, nose, ear, head, and submaxillary and cervical regions. Patients undergo a certain amount of mental shock, and are weak through fatigue, toxic absorption from the wounds, and lack of sufficient nourishment, the last being due to inflammation of the soft tissues and derangement of the organs of mastication.

Furthermore, a considerable proportion of cases have reached the hospital in a seriously ill condition because of additional injuries, such as penetrating wounds of the head and chest, fracture of the long bones, or multiple and extensive flesh wounds. Others have already contracted pneumonia previously to their admission.

All of these complicating circumstances have an influence on the mode of treatment employed when hæmorrhage ensues.

Frequency and Time of Hæmorrhage.—Of a total of 34 mild and serious hæmorrhages occurring among the 400 cases (8·5 per cent), 16 required operative measures for control under a general anæsthetic, while the remaining 17 were successfully treated by packing, clamping, or by the use of a local anæsthetic for ligation of the bleeding point. One case died suddenly from very profuse hæmorrhage.

The majority of secondary hæmorrhages took place between the fourth and twelfth days after injury, three between the thirteenth and nineteenth

* We desire to express our indebtedness to our colleague Lieutenant F. Brigham, of the Harvard Surgical Unit, for kind assistance in preparing this paper.

days, and only one after this period, namely, on the forty-fifth day (*Fig.* 71). In the last case both superior maxillæ and the base of the skull were fractured (*Case* 21).

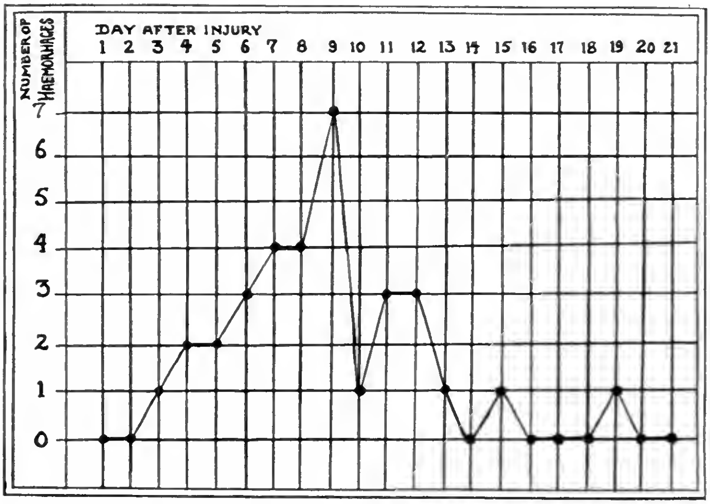


Fig. 71.—Chart showing the days of occurrence of secondary hæmorrhage.

It is interesting to note that most of the secondary hæmorrhages appeared during the night or early afternoon (*Fig.* 72); that is to say, during the hours of sleep. This is a curious fact, for it might have been expected

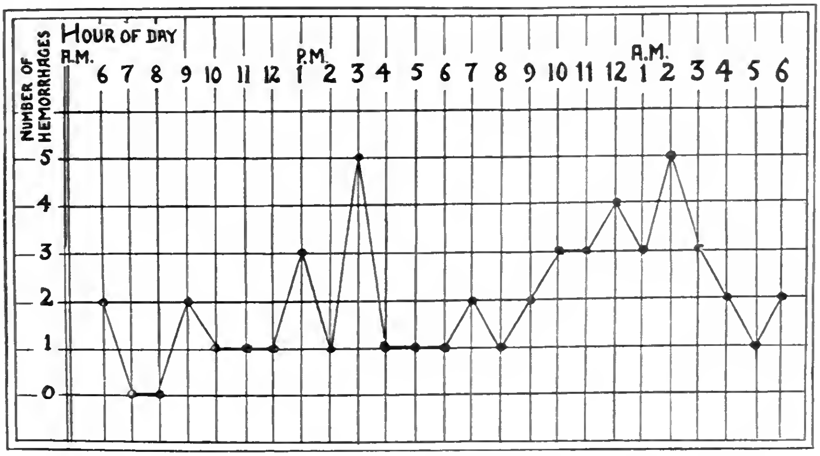


Fig. 72.—Chart showing the hours at which secondary hæmorrhage took place.

that the disturbances of feeding, dressing the wounds, taking impressions, or the fitting of appliances, would be the causes of recurrent bleeding from an injured vessel. Two cases of hæmorrhage have occurred within a few minutes

of the arrival of relatives at the bedside. Even if this were mere coincidence, it serves as a warning to minimize all likelihood of mental excitement on the part of any patient in whom bleeding is likely to occur.

The fact of the complication taking place at night, when the staff is attenuated, adds to the difficulty of treatment. The loss of blood may be profuse enough to bring on collapse with great swiftness, as in *Case* 29, where, though the medical officer was in attendance almost at once, the patient was already in a dying condition.

Sources of Hæmorrhage.—It is not always possible to determine the artery which is responsible. The surgeon is guided by a comparison of the anatomical distribution of the blood-vessels with the extent and direction of the entrance and exit wounds and with the injury caused to the soft tissues.

Injuries to the superior maxilla and other bones of the upper half of the face are often accompanied by nasal bleeding from the deeper structures,

Figs. 73, 74.—Photographs (*Cases* 14 and 28) illustrating the type of case in which hæmorrhage is to be expected. *Fig.* 74 is a defective photograph, but it illustrates the appearance in question.

which arises probably from the branches of the internal maxillary artery. Amongst 91 cases of fracture of the upper jaw, there were four hæmorrhages: in three of these the bleeding was easily controlled by packing, while in the remaining one it was serious and persistently recurrent (*Case* 21).

One case of bleeding from the anterior palatine artery has arisen, which was arrested by ligation under a local anæsthetic. Hæmorrhage from the main trunk of the internal maxillary artery is rarely or never met with.

In 7 cases of extensive laceration of the face, bleeding from the mouth has occurred. In all the hæmorrhage was superficial, with the source of bleeding exposed, and it was stopped by packing, by the application of clamps, or by the immediate ligation of the vessel under a local anæsthetic.

In those cases where the wounds are below or behind the angle of the lower jaw and involve the pharyngeal cavity and the neck, it is difficult to decide by internal examination which side is responsible for the bleeding. There were three such cases of hæmorrhage from the pharynx, two of which were fatal (*Cases* 25 and 29).

Bleeding which occurs as the result of extensive wounds of the molar and bicuspid section of the lower jaw, where there is an accompanying injury to the floor of the mouth, usually arises from the lingual artery or its branches. Such cases have been the most common, and likewise the most serious, as is shown by the fact that from a total of 34 hæmorrhages, 17 came from this source; and of this latter number, 12 required operative means of control under a general anæsthetic.

Certain cases which presage hæmorrhage from the lingual artery have recognizable characteristics. The wounds of entrance and exit are usually

FIGS. 75, 76.—Photographs of extensive injuries, illustrating cases in which serious hæmorrhage is not likely to arise.

small, and situated in the vicinity of the posterior half of the lower jaw. The tongue is perforated, often dark purple in colour, and swollen to twice or three times its normal size, so that in spite of the open position of the mouth, it protrudes beyond the lips. The jaw is fractured bilaterally, and the anterior segment shows a pronounced downward displacement. *Figs.* 73 and 74 are typical of the appearance of a case in which bleeding is to be anticipated.

On the other hand, large wounds anterior to the bicuspid region are unlikely to presuppose serious hæmorrhage, since the area affected is supplied only by smaller branches of the important arteries.

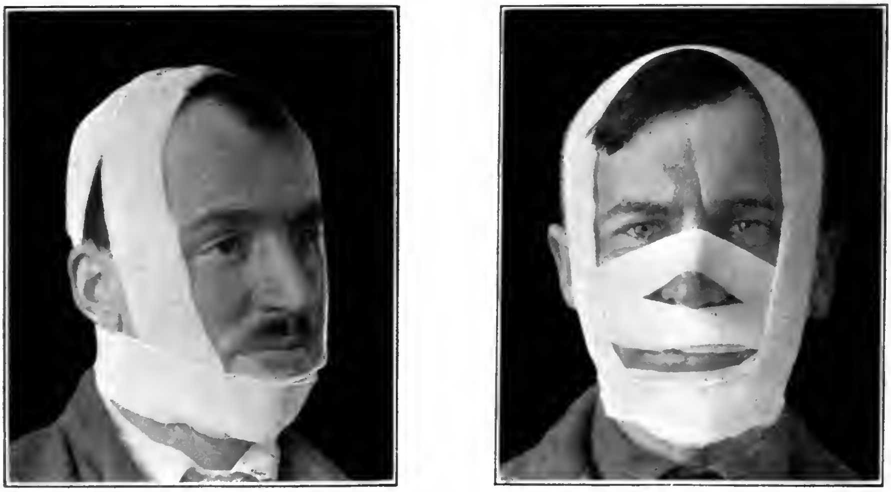
Extensive injuries, with destruction of the hard or soft tissues, but which are open, are less prone to bleed, because the free drainage forestalls the spreading of sepsis (*Figs.* 75, 76). Even with hæmorrhage from such a wound, it is usually possible to seize and ligate the vessel which is responsible.

Those perforating wounds of the neck which involve the pharynx are serious, in that irrigation and the establishment of drainage may be difficult, and the patient finds it an effort to breathe, to clear the throat, or to take nourishment, even with tubes.

TREATMENT.

This will be discussed under the headings of (1) *Preventive treatment*; (2) *Immediate treatment*; (3) *Operative treatment.*

1. **Preventive Treatment.**—Assuming that the recognized causes of hæmorrhage are—direct injury to the vessels, the spreading of sepsis due to the absence of free drainage, the presence of foreign bodies and splinters of bone, and mobility of the bony parts: then active measures should be taken to combat them. To overcome the uncleanliness caused by inflammation, suppuration, food deposits, and excessive salivation, the teeth and all mucous surfaces of the oral cavity are swabbed with cotton pledgets saturated with



Figs. 77, 78.—Barton bandage.

tincture of iodine, followed by hydrogen peroxide; and then such solutions as potassium permanganate, boric acid, or listerine, are used to irrigate all parts of the mouth.

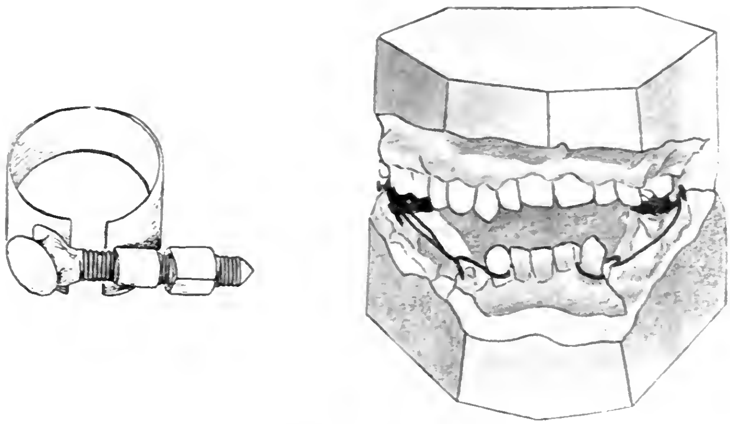
The removal of detached fragments of bone and affected teeth or roots is an essential factor in the control of sepsis. Infiltrative or conductive local anæsthesia about the oral cavity, with 2 per cent solution of novocain, may be employed through all stages of treatment; especially during the early days, when the consequences of general anæsthesia are to be avoided. The patient is more comfortable, and fed or dressed with less inconvenience, if he is kept in a semi-sitting position in bed. In the event of bronchitis or an irritating cough which tends to submit the muscles of the throat and face to undue exertion, immediate medical attention should be given. Liquid food

is administered through an œsophageal or a nasal tube; and if a pharyngeal injury prohibits this measure, rectal feeding is indicated.

In spite of the illness of the man, the jaw should have some sort of temporary support. This point is especially important, as it has been observed that the cases most prone to bleeding are accompanied by fractures of extensive displacement and mobility, with consequent enlargement of the wound and irritation to soft tissues.

The following are some of the simpler methods for securing comparative immobility of the jaw:—

The Barton bandage (*Figs.* 77 and 78) is an effective support when properly used. It is put on as follows: Starting a little to one side of the occipital region, the bandage is passed upward and forward across the head; it is then continued downward in front of the opposite ear, under the point of the chin, up the opposite side of the face, and diagonally to the back of the neck. Thence it passes around the neck below the ears, and across the chin to its starting point. After a part of the bandage has been put on in this



Figs. 79, 80.—Angle's bands.

way, the horizontal turn which covers the chin may be modified to include wounds of the lips, nose, eyes, or forehead.

Angle's bands (*Figs.* 79 and 80), as manufactured for immediate use in cases of fractures of the jaw, can be fastened to selected teeth for attachment of temporary wire or silk ligatures. The displacement may be reduced by approximating the fragments laterally, or by anchorage to the upper jaw.

In other cases, brass wires (No. 25 American gauge) may be attached to the necks of opposing teeth and then twisted together; by leaving the ends uncut and emerging from the lips for four or five inches, the surgeon or attending nurse can untwist the wires to feed the patient or to clean the mouth (*Fig.* 81). The same end may be accomplished by twisting brass wires on to the teeth, with the ends cut short and turned over so as to form hooks between which small elastic bands are used to bring fragments of the jaw into approximate position (*Fig.* 82).

In any instance, if the facilities are at hand, dental splints or appliances should be used at as early a time as the patient's condition will permit.

In adjusting any splint, either temporary or permanent, the former occlusion of the teeth must serve as a guide, and any force applied must tend to reproduce this condition. The teeth existing on either side of the fracture serve as an anchorage, or if absent on one side, then the teeth of both upper and lower jaws are utilized.

Fig. 81.—Jaws fixed by temporary wires, with ends of wires emerging from the mouth.

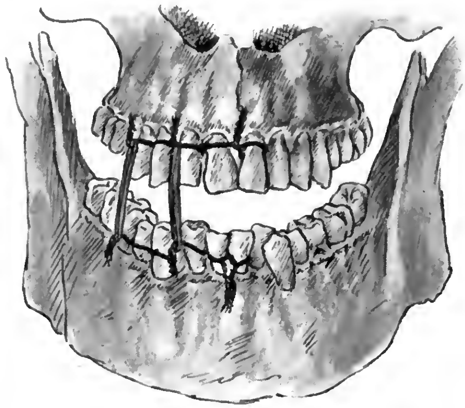


Fig. 82.—Jaws fixed by brass wires and rubber bands.

2. **Immediate Treatment.**—The seepage of arterial blood, which in most cases precedes a serious hæmorrhage, is almost the only anticipatory indication of value. Bearing this fact in mind, it is important that the surgeon should give the patient a careful examination immediately on admission, to determine the precise nature of the wound. Indeed, the exact area from which bleeding might be expected should be considered beforehand.

In the event of an emergency, the tray used in the ward for dressings may be depleted at the moment when it is most wanted, and therefore a separate one should always be kept in readiness, with swabs, ribbon gauze, artery clamps, sinus forceps, dental mouth-mirrors, a head-mirror, adrenalin chloride, hydrogen peroxide, etc.

As soon as the hæmorrhage appears, the attending nurse should send for the medical officer, and while awaiting his arrival, should syringe the patient's mouth with hydrogen peroxide, and attempt to control the bleeding with digital pressure. The patient should be kept sitting in bed against a back-rest, to facilitate the work, to reduce the blood-pressure in the head, and to prevent the flow of irrigating solutions and blood into the throat. The use of hydrogen peroxide gives a clean field of operation in the shortest time, and acts to a slight degree as a hæmostatic. Following this, the area is swabbed

rapidly, and that part from which blood issues is packed tightly with gauze soaked in adrenalin chloride.

As an adjunct to packing, a specially devised clamp will be found useful. This consists of a heavy piece of wire from eight to ten inches long, bent to a U shape, with a 'finger' or pad of dental modelling composition or vulcanite rubber on each end (*Fig.* 83). The clamp is adapted by bending it so that one end presses over the packing, while the other presses externally at a corresponding point under the chin between the hyoid bone and the lingual aspect of the mandible (*Fig.* 84). Ligatures or elastic bands about the arms of the clamp will give the desired amount of pressure. A clamp of similar pattern, but of reduced dimensions, serves for the arrest of hæmorrhage from the facial artery, exactly as one would pinch it with the thumb on the cheek and the forefinger inside the mouth.

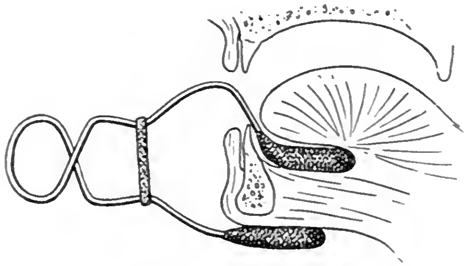


Fig. 83.—Lingual artery clamp.

It must be remembered that even though the act of packing may not be the final means of stopping the hæmorrhage, nevertheless it must be carried out to control it for the moment, and to minimize the chances of recurrence before ligation is effected.

3. **Operative Treatment.**—Suppose a case of recurrent or secondary hæmorrhage following a gunshot wound of the lower jaw; a case in which on account of its volume or frequent recurrence, the bleeding requires for its permanent arrest more conclusive measures than the fixation of the jaws and the packing of the wound: and let us discuss the operative treatment.

Fig. 84.—Patient with lingual artery clamp applied.

Three courses are open for consideration, namely: (1) *Ligation of the responsible vessel at the bleeding point:* (2) *Ligation of the vessel at some spot proximal to the bleeding point:* (3) *Ligation of the external carotid artery.*

Ligation of the common carotid artery is not included in the measure for cogent reasons. Although to secure the external carotid, with the patient in a desperate condition from loss of blood, is a difficult and perhaps protracted operation, and although there may arise in consequence a temptation to forgo the attempt and to tie the common carotid instead, because of the speed and ease with which this may be accomplished, nevertheless this expedient has been condemned entirely by experience. In the first place, we are often in doubt as to which side the

bleeding artery belongs. In the presence of such uncertainty, ligation of the common carotid is open to grave and obvious criticism. As a primary method of arresting hæmorrhage from the tongue or its neighbourhood, occlusion of this vessel is likely to fail in achieving success, owing to the abundant supply of blood in the external carotid through the collateral channels, including the circle of Willis. Moreover, the percentage of cases in which grave cerebral disorder has followed primary ligation of the common carotid is so high as to render the operation unjustifiable, except as an ultimate effort, when other means have failed. Probably the anæmia and shock which exist at the time of operation are largely responsible for the bad results. On four occasions we have been driven to tie the common carotid. Three of the patients died, and the one who recovered suffered from hemiplegia with aphasia (*Case* 23), a history which needs no further comment.

We will proceed to deal with the three legitimate operations which we have defined already, and will endeavour to separate the groups of cases to which each one has special application.

1. Ligation at the Bleeding Point.—The first proposal is to find and secure the bleeding point, for this is a rule of surgical practice established by the wisdom of our forefathers, and perpetuated by our own experience of its merit. This, which may be regarded as the ideal course, is available in certain cases, most of which are of lesser severity.

The following are the four varieties of cases in which an endeavour to secure the bleeding point is the correct practice.

a. Those in which the Bleeding is External.—Here the blood is not effused into the mouth, and the injured vessel may be sought for without any invasion of the buccal cavity. Injuries of the facial artery, or one of its branches, submental or coronary, provide most of the examples.

b. Intrabuccal Hæmorrhage of Small Volume.—In these cases the bleeding is not sufficiently profuse to obscure the field of operation, or cause much harm to the patient if allowed to continue during a brief local investigation. Such a hæmorrhage may come from an artery of the frenum, one of the palatine arteries, or some other small branch of the lingual, facial, or internal maxillary.

c. Copious Hæmorrhage from the Free Portion of the Tongue.—This arises from the ranine artery, and the bleeding is often alarming owing to the abundant flow. Temporary arrest, however, may be effected readily by placing a pad of gauze under the tongue, and pressing the tongue on the pad by means of a finger held firmly on the dorsum. The artery is easily accessible from the mouth for purposes of ligation.

d. Profuse Intrabuccal Hæmorrhage from the Floor of the Mouth when the Face is opened sufficiently to allow a good view of the Deep Tissues at the Base of the Tongue.—These cases are not common. The bleeding point can be looked for directly, because of the open nature of the wound. Another favourable feature is that the effused blood flows freely from the buccal cavity owing to the wide extent of the injury, and so does not cause the special difficulties which arise from the presence of a continual well of blood in the mouth.

One occasional source of difficulty in all these emergencies lies in the cessation of the hæmorrhage during operation; a contingency that is to be

expected if local anæsthesia be used, but which sometimes takes place also with general anæsthesia. Even rubbing the wound with gauze, and other local stimulation, may fail to reproduce the bleeding, with the result that the offending vessel cannot be located. Accurate observation of the wound while bleeding is still in progress may do something to mitigate this annoyance, but even careful preliminary investigation will not enable us always to avoid failure from this obstacle. The only remedy left is to examine the wound for any adherent clot, and by tracing it gently and minutely, endeavour to find the vessel from which it has originated.

FIG. 85.—Radiogram showing numerous fragments of shell, teeth, and bone scattered through the tissues.

2. LIGATION OF THE BLEEDING ARTERY AT A POINT PROXIMAL TO THE INJURY.—In cases where ligation of the bleeding point is impracticable—and in the majority of profuse intrabuccal hæmorrhages from the floor of the mouth such a course *is* impracticable—we have to adopt other tactics. Our first plan is to secure the injured artery at some point proximal to the seat of trauma. Here again, however, certain difficulties arise, the first of which is to recognize which artery is responsible. We have to consider eight possible

sources, four on each side—namely, the lingual, inferior dental, facial, and lastly, the external carotid itself, with its tonsillar, pharyngeal, and other branches. In some cases, especially where the entrance and exit wounds are small, we cannot definitely exclude any of these, either by anatomical study of the wound or by other means: for example, a through-and-through wound about the angles of the lower jaw. And even here, when some of the sources mentioned can be almost or quite excluded, we still are faced with sufficient doubt in trying to form an opinion as to the degree of responsibility resting on the remainder. Only too often we are quite unable to discover with certainty even from which side the hæmorrhage comes. Attempts to settle this seemingly simple question by arresting bleeding momentarily with pressure exerted alternately on the right and left carotids in the base of the neck, have failed.

Fig. 86.—Photograph of same patient as in *Fig.* 85.*

Anatomical considerations founded upon the situation of the wounds and the track of the main projectile are often vitiated by the fact that a bullet or fragment of shell, passing through the jawbone or striking the teeth, converts pieces of these tissues into secondary projectiles, which scatter and so cause damage to structures lying away from the main path (*Figs.* 85, 86).

Another complication which adds to the confusion is the occasional presence of simultaneous damage to two or more arteries. This association of injuries is not uncommon. The two lingual arteries are not far apart in the root of the tongue, and frequently participate in a common injury.

Broadly speaking, we may say that (*a*) Bleeding from the floor of the mouth comes from one or both lingual arteries or their branches; (*b*) Bleeding from between the fragments of a broken lower jaw arises from the inferior dental; (*c*) Bleeding from the cheek or lip has its origin in a branch of the facial; and lastly, (*d*) Bleeding from the pharyngeal and tonsillar regions will call for ligation of the external carotid artery.

If the lower jaw were intact, and the soft tissues in their normal relationship, this approximate localization would not be such a very hard matter. But in the cases under discussion the lower jaw is fractured—often in more than one place—and comminuted, while the tongue and other soft tissues may be much swollen by infiltration with effused blood and the products of

* In this case the right lingual and left external carotid were ligated in order to avoid hæmorrhage, although none had occurred previously to the operation. It is the only instance in which we have employed prophylactic ligature. The result justified the measure, for bleeding was to be anticipated, and the patient was so ill, that had operation been postponed until the hæmorrhage came about, there could have been little or no hope of saving his life.

inflammation. Moreover, as often happens in wounds of other parts of the body, the hole through which blood escapes may be remote from the point of vascular injury, to which it is then a false guide.

Again, a case which at one time appears simple may prove a dilemma. For example, the mandible is fractured at the bicuspid region, and blood is escaping from the cleft between the cheek and the alveolus. Is the facial or the inferior dental to blame?

However, these difficulties in locating the source of bleeding must not be exaggerated. They are considerable, but they do not rob anatomical estimates of all their value.

At first sight there might seem to be an easy way of avoiding all difficulties by ligation of the external carotid artery, because this would block the supply of all arteries of the same side which could be concerned with the trouble. After we had suffered some preliminary failures, and had met with cases in which bleeding recurred after ligation of the artery which we had thought to be the one concerned, we adopted this course of ligating the external carotid; but before long we had reason to revert to the former practice. We learned that ligation of the external carotid in these cases was attended by considerable difficulty and danger. We learned also that profuse recurrent hæmorrhage from the floor of the mouth nearly always arose from one or both lingual arteries or their branches. Consequently, our procedure in all copious hæmorrhages from this latter area, occurring in connection with gunshot wounds of the lower jaw, is to ligate one or both lingual arteries, provided the anatomical conditions are compatible with a wound of these vessels.

To assume that the lingual is the source, and to act on this assumption, may seem at first thought to be unsound; and probably most surgeons would feel inclined to hesitate before basing an operation upon such a guess-work diagnosis. However, improved results and a lowered mortality have convinced us that this practice is more than justified, and that it is indeed the right and proper method to adopt. Even when subsequent events prove that we have tied the wrong vessel, and another loss of blood points to the inferior dental as the source, probably we shall have avoided placing the patient's life in jeopardy; for bleeding from the latter artery, although it may be alarming, is not so copious as from the lingual, and is more easily controlled by packing while arrangements are being made to place a final check by a further operation. The following table shows the comparative results:—

Artery Ligated	Number of Cases	Deaths	Mortality
External carotid ..	10	5	50 per cent
Lingual	6	1	16·6 ..

We have discussed the difficulties connected with this matter at some length, because the discussion maps out the road along which we have travelled ourselves, and therefore may be of assistance to others who journey in the same direction.

3. Ligation of the External Carotid Artery.—This is the final resort, and for more than one reason must be placed last on the list of available methods.

Experience has shown that ligation of the external carotid does not always finally dispose of the danger of bleeding. For, whether due to direct injury of a vessel of the opposite side, or to the collateral circulation which is so free in these parts, the fact remains that in a fair proportion of cases bleeding has recurred after ligation of the external carotid (*Cases* 2, 23, 28). Moreover, as will be seen later, ligation of this vessel in the presence of a compound fracture of the lower jaw due to a gunshot wound is formidable and dangerous.

OPERATIVE TECHNIQUE.

1. **Hæmorrhage from the Inferior Dental Artery.**—Analogy with the consequences of fractures of other bones would lead us not to expect recurrent hæmorrhage from the inferior dental artery after fracture of the lower jaw. However, we have had one case in which such an event certainly took place, and in which the bleeding was sufficiently persistent and profuse to endanger the patient's life (*Case* 9). This illustrates the great difficulty there may be in recognizing the source of a hæmorrhage. The lower jaw was fractured, and there was a gap in the alveolar margin through which the blood was escaping. We considered the possibility that this might come from the inferior dental, while, judging from the track of the wound, it might equally well come from the lingual or facial. The entry wound in the face was healed, and consequently, had the facial artery been responsible, the blood would have escaped through the buccal wound. At first we favoured the facial artery rather than the lingual, because the blood seemed to come from the outer side of the gap in the jaw, rather than the inner side. The recurrence of bleeding after ligation of the facial led us next to tie the lingual, for the volume of escaping blood was, as we thought, too large to originate from the inferior dental. And it was not until we had secured both the facial and the lingual, that we realized the actual source of the bleeding. It is probable, in view of the repeated recurrence of bleeding in this case, that the inferior dental had not been completely severed in the wound. This we could not ascertain, for in dividing the callus we divided the artery also.

Access may be obtained to the inferior dental artery by trephining the lower jaw-bone in the same manner as described in text-books for exposure and division of the inferior dental nerve. But we have not had occasion hitherto for adopting this manner of approach.

2. **Ligation of the Lingual Artery.**—The lingual artery arises from the external carotid near the hinder end of the great cornu of the hyoid bone. The first part is not overlapped by muscle other than the platysma, and extends from the point of origin of the vessel to the place where it passes under the digastric and stylohyoid muscles. The second portion is covered by the digastric and stylohyoid, and further forward by the hyoglossus. Both the first and second portions rest immediately upon the middle constrictor of the pharynx. The third portion passes up between the hyoglossus and the genioglossus, and upon reaching the free part of the tongue is continued on its under surface to the tip as the ranine artery.

Note must be made of the fact that the third part of the lingual artery is rather close to its fellow of the opposite side, from which it is separated only by the two flattened masses of the genioglossus muscles, an approximation which explains the frequent concurrence of injuries to both linguals in this region.

From the second portion arise one or more dorsal lingual arteries, which supply the dorsum and back part of the tongue and epiglottis. The third portion, that is to say the part lying in the floor of the mouth between the anterior border of the hyoglossus and the commencement of the ranine artery, is the source of most of the severe hæmorrhages with which we have to deal. In this situation the artery lies too deeply to be approached by operation from the neck; and we have mentioned already how difficult and unpractical it is to attempt to find the bleeding point itself in the floor of the mouth. The suggestion has been made that the vessel could be secured by passing a curved needle, threaded with ligature, deeply into the floor of the mouth, so as to include the third part of the lingual together with a substantial amount of the musculature of the tongue. Apart from the obvious objections to such massive ligation in a septic wound of the mouth, the plan is not likely to succeed in securing the artery, for anatomical reasons; the artery, its direction being upward and forward, is likely to elude the embrace of the ligature, unless a bulk of muscle be included which would be altogether inadmissible. Therefore we may dismiss as not feasible all operative attempts to arrest hæmorrhage by securing the third part of the lingual artery, by approaching it either from the neck or through the mouth. The ranine artery, as we have demonstrated already, may be caught without difficulty from the mouth (*Case* 10). Ligation of the first and second parts respectively, therefore, remains to be considered.

The incisions required for these two operations are different, and our own judgement as to whether we shall ligate the first or second part will be determined in many instances by the position of the external wounds. For we shall endeavour to place the operation wound as remote as possible from the gunshot wound, in the hope of thereby obtaining clean healing of the former. An additional factor comes into play. The dorsalis linguæ arteries arise from the second part, and if the tongue is wounded far back, we shall wish to be certain of securing these vessels, in which case we shall select the first part for the application of the ligature.

a. Ligation of the First Part of the Lingual.—With the patient supine, his face inclined to the opposite side, and the neck extended over a sand-bag, an incision is made along the anterior border of the sternomastoid, the centre of the incision being opposite the great cornu of the hyoid bone. The sternomastoid having been exposed, the deep cervical fascia is divided parallel with its anterior border. The carotid triangle is thus uncovered. Within this triangle are the external carotid artery and its branches. They are concealed, however, by areolar tissue, lymphatics, and certain veins, of which the common facial and the lingual, with their tributaries, chiefly concern us. There may be a temptation to try to expose the lingual artery by retraction of these veins. Unless, however, the exposure is quite easily accomplished in this way, it is better to divide and tie any veins that obscure our view. Time

ought not to be wasted in attempting to preserve any vein which lies in the way of a clear and unembarrassed field. The external carotid artery is now exposed, with the superior thyroid, lingual, and facial arteries successively arising from its anterior wall a short distance above the bifurcation. The landmarks that must now be identified clearly are: (1) The posterior end of the greater cornu of the hyoid bone; (2) The posterior belly of the digastric, with the stylohyoid muscle; (3) The hypoglossal nerve. All these are rapidly recognized (*Fig.* 87). The lingual artery is then traced upward and forward to where it passes deeply to the hyoglossus, stylohyoid, and digastric muscles. Two ligatures are applied at this point, and the artery is divided between them. The reason for tying the artery so far forward is to allow a sufficiently long stump between the proximal ligature and the external carotid artery.

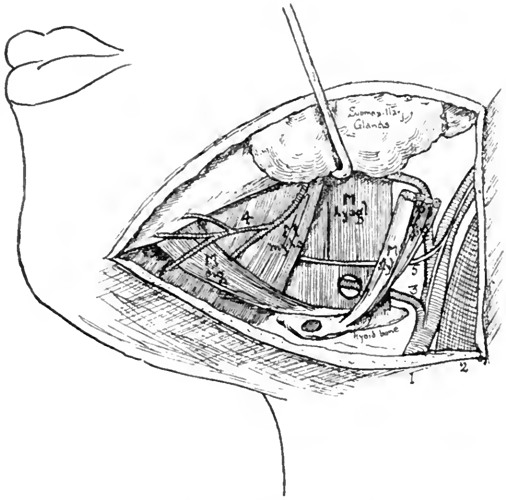


FIG. 87.—Diagram showing anatomy of the lingual artery. The submaxillary gland has been drawn over the side of the jaw with a hook. (1) External carotid artery; (2) Jugular vein; (3) Lingual artery (shown also in window in hyoglossus); (4) Submental branch of facial artery; (5) Hypoglossal nerve; M. dig. Anterior belly of digastric muscle; M. styl. Stylohyoid muscle; M. myho. Mylohyoid muscle; M. hyogl. Hyoglossus muscle; P. dig. Posterior belly of digastric muscle.

b. Ligation of the Second Part of the Lingual. — The patient is arranged on the table in the same posture as for ligation of the first part. A curved incision is made, commencing half an inch below the mental tubercle, passing downward and backward to the hyoid bone or the upper border of the thyroid cartilage—according to the amount of displacement of the jaw—and then upward and backward to the sternomastoid muscle. The flap thus formed is turned up, and the deep fascia is divided in the line of the original incision. The submaxillary gland is retracted upward so as to expose the floor of the submaxillary triangle, and the following landmarks are identified: (1) The anterior and posterior bellies of the digastric, with their intervening tendon; and (2) The hypoglossal nerve, lying on the hyoglossus muscle, and crossing the angular space between the two bellies of the digastric to pass under the mylohyoid muscle (*Fig.* 87). The hyoglossus is then cut through midway between the hypoglossal nerve and the greater cornu of the hyoid bone, the line of incision being parallel to the latter structure. This will expose the lingual artery, which is then tied in two places, and cut through between the ligatures.

SPECIAL DIFFICULTIES.—The displacement of the broken jaw and the swelling of the neighbouring structures lessens the freedom and ease of exposing the lingual artery in many cases, nor is one helped very much by

attempting to raise the lower jaw (*Figs.* 88, 89, 73, 74). In particular, the submaxillary salivary gland and the lymphatic glands in the submaxillary triangle are apt to form a solid, unyielding mass which lies in the way of a good view of the lingual artery. In some such cases retraction of these structures is unavailing, and it will then be found of great assistance to resect them: a manœuvre which does not materially lengthen the operation, while it greatly

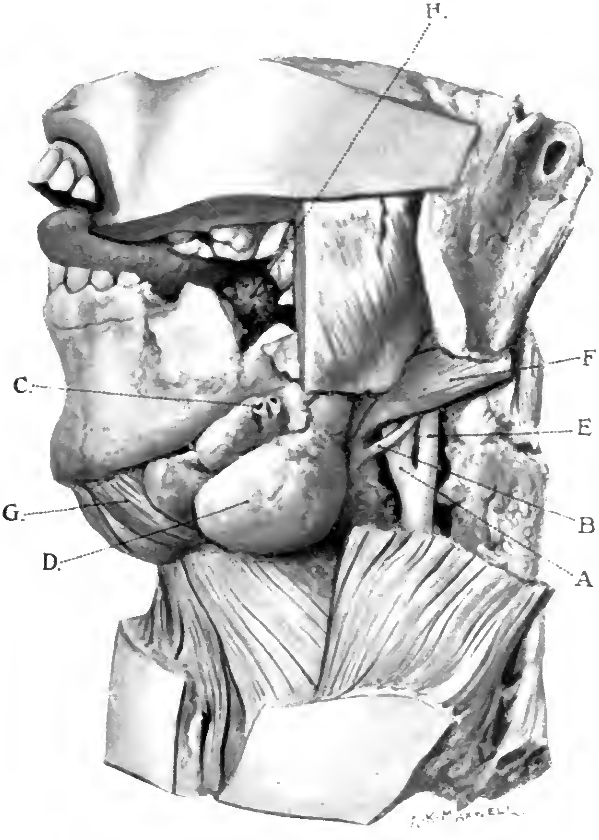


FIG. 88.—Drawing from dissection of a case of bilateral fracture of the mandible due to gunshot wound. The illustration shows the dropping of the anterior portion of the mandible, and the manner in which the glands overlap the submaxillary triangle and render it difficult to expose the second part of the lingual artery. (A) External carotid; (B) Hypoglossal nerve; (C) Facial artery and veins; (D) Submaxillary salivary gland; (E) Internal carotid; (F) Posterior belly of digastric muscle; (G) Anterior belly of digastric; (H) Clot protruding from the exit wound in tongue.

facilitates exposure of the lingual artery in the second portion. We have had to carry out this detail in two instances (*Cases* 7, 9).

Another trouble is the depth at which the artery lies. This can be countered by the assistant, who, with his hand placed on the other side of the patient's neck, presses the hyoid bone up into the wound.

On one occasion (*Case* 7), the second portion of the lingual artery could

not be seen after the hyoglossus had been divided. The first portion was therefore sought, and it was found that the lingual arose from the external carotid at a higher level than usual, forming a common trunk with the facial. In this position it was easily identified and secured.

3. **Ligation of the External Carotid.**—The incision and subsequent stages of this operation up to the point of exposure of the vessel, resemble those of the ligation of the lingual in its first portion, as already described. The spot usually chosen for the ligature is between the places of origin of the

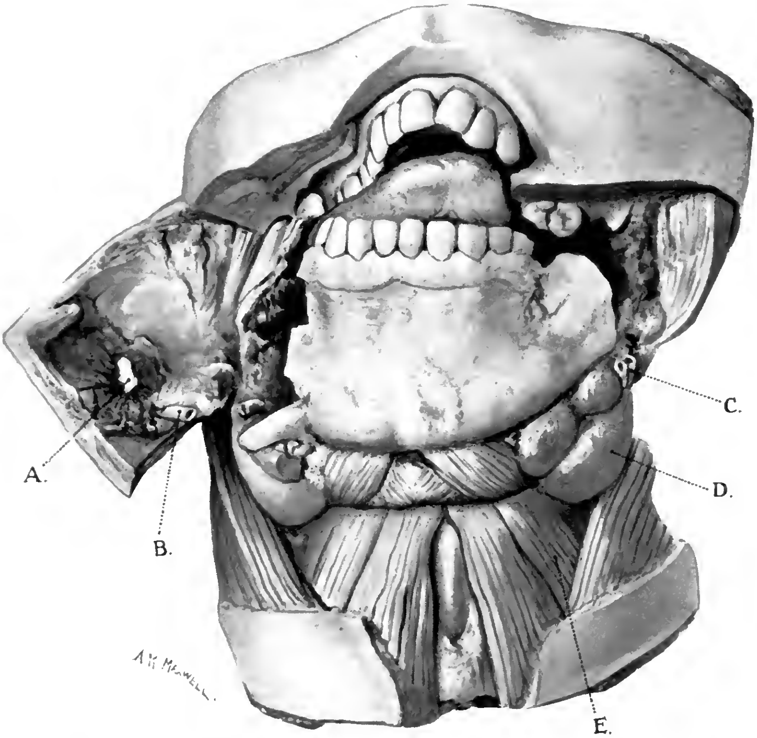


Fig. 89.—Anterior view of the dissection shown in *Fig.* 88. Shows the characteristic jaw-drop which follows bilateral fracture of the mandible. (A) Entry wound as seen from inner surface of reflected flap; (B) Facial artery completely divided in wound without causing secondary hæmorrhage; (C) Left facial vessels; (D) Submaxillary gland; (E) Omohyoid.

superior thyroid and lingual. But it may be well to tie the artery at a higher level than this—the lingual being tied off separately—in order to provide a longer stump between the ligature and the common carotid artery. The object of this is to avoid the protrusion of clot into the blood-stream of the common carotid, with the subsequent dangers of cerebral embolism. We had such a catastrophy in one instance (*Case* 30).

General Dangers and Difficulties.—There are certain drawbacks and difficulties in these operations for ligation of the lingual and external carotid arteries: and they deserve special comment.

Sepsis.—In the first place attention must be called to the fact that the operation wound is likely to become infected in a number of instances, owing to the proximity of the gunshot wound, together with the difficulty of keeping the operation wound dry during the ensuing days because of the continual dribbling of saliva in its neighbourhood. This consideration will lead us to make an incision, if we have any choice in the matter, as far away as possible from any pre-existing wound ; and it may be the chief factor in determining whether to tie the first or the second part of the lingual.

Further, the possibility of sepsis ensuing renders necessary the application of two ligatures to the vessel concerned, which is then divided between them ; otherwise, in a septic wound ulceration may set in, with a repetition of bleeding at the site of the ligature. Division of the artery between two ligatures permits retraction of the two ends, and forestalls this danger. We have had two examples (*Cases* 23, 25) in which secondary hæmorrhage occurred from the external carotid after the application of a single ligature, the artery having been left undivided.

Venous Hæmorrhage.—The chief difficulty in exposing the artery to be tied is due to the numerous large veins which intervene. Time will be saved and no harm done by the division of such as obscure our view. The common facial is the largest of them. The hindrance caused by these veins will be diminished if a free air-way is provided for the patient's respiration—a matter which will be discussed under the heading of "General Anæsthesia"—or if local anæsthesia be used.

All veins which are divided should be secured effectively before the wound is sewn up, because, in the absence of this precaution, there may be post-operative venous bleeding into the tissues of the neck, especially if the patient vomits. An additional precaution against this will be to remove the sand-bags from beneath the patient's neck, so as to relax tension and allow any unsecured veins to bleed before the wound is closed up. Fear of sepsis need not prevent us from suturing the deep fascia except where room must be left for drainage.

Displacement of Anatomical Relations.—There may be some disturbance of the normal relationship of the soft structures in the operation area through swelling from hæmorrhage or inflammation due to sepsis. But the chief displacement is the dropping of the jaw (see *Figs.* 73, 74, 88, 89). The elevators of the lower jaw are attached to the hinder portion of that structure, while the depressors are attached to the anterior portion. Consequently, in a double fracture of the mandible, which is not uncommon in these cases requiring operation for the arrest of hæmorrhage, the anterior portion of the jaw is pulled downward and backward. This dropping is not only a source of trouble to the anæsthetist (as will be mentioned again later), but is also a great inconvenience to the surgeon. The displaced jaw cannot be raised completely into its proper place by pressure applied to the chin or by traction on the incisor teeth, and the field of operation is therefore encroached upon. The necessity for excising the submaxillary gland when seeking to tie the second part of the lingual artery is chiefly due to this cause. And whether the external carotid or the lingual is to be ligated, one is apt to think at first that these vessels originate at a higher level than is actually the truth, and to

imagine that there is an abnormally high bifurcation of the common carotid—an error that is perceived as soon as the relative positions of the bifurcation and the upper border of the thyroid cartilage are examined (*Figs.* 88, 89).

Miscellaneous Drawbacks.—Probably it is well to avoid cutting into the lower portion of the parotid gland, though we have not observed any case in which this act has caused trouble through the escape of parotid secretion.

We have known a case in which the external carotid was wounded in the attempt to pass an aneurysm needle around it, with the consequence that the surgeon was forced to ligate the common carotid. We have also had a case in which the pharynx was perforated during an operation for ligation of the external carotid. Both the external carotid and the lingual arteries lie immediately upon the middle constrictor of the pharynx, and the latter is quite a thin structure. Consequently the danger of causing a pharyngeal fistula is not negligible.

We have referred already to cerebral embolism following ligation of the external carotid (*Case* 30), and also to the possibility of secondary hæmorrhage from the latter due to ulceration of its wall at the site of the ligature when the vessel has been ligated in continuity (*Cases* 23, 25).

Recurrence of Hæmorrhage from the Gunshot Wound.—This distressing sequel may be attributed to one of three causes: (1) We may have tied the wrong artery (*Cases* 2, 9, 23); (2) More than one artery may have been injured originally. The two lingual arteries come fairly close together in the mouth, and we have found both to be injured in more than one instance (*Cases* 14, 28, 30), and have suspected the coincidence in others; (3) The recurrence may be due to collateral circulation, in which case it is unlikely to be severe, and probably will be amenable to such simple measures as clamping or packing.

Shock.—Especial care must be taken to provide against shock. Owing to the severity of the original wound, loss of blood, and sometimes to concomitant injuries, these patients are liable to suffer severely and readily from shock. In a case where both linguals were tied, the patient died four hours later from this cause (*Case* 26). We have had other cases in which, although the patients did not die, the post-operation shock was considerable.

A word of warning is necessary with regard to the administration of morphia to patients who are suffering from the immediate results of copious hæmorrhage. This drug has an exaggerated effect on patients in this condition, and if any is given, it must be in smaller doses than those used for full-blooded persons. We have thought that the administration of morphia has another drawback, in that it seems to favour the development of bronchopneumonia—possibly by lessening the activity of the laryngeal reflex.

Bronchopneumonia.—One of the most serious complications of gunshot wounds of the jaw is septic bronchopneumonia. And the evidence is sufficiently clear that a frequent cause is the inhalation of septic material during anæsthesia. We believe also, as already mentioned, that morphia plays a similar part to chloroform or ether in this respect. Much of the danger of causing bronchopneumonia is avoided by employing local anæsthesia whenever possible.

General Anæsthesia.—The main precautions to be observed are two: (1) The avoidance of inhalation of septic material from the mouth into the respiratory passages; and (2) The provision of a perfectly free air-way for the patient, so that there will be no violent efforts to breathe, and no unnecessary engorgement of the veins of the neck to increase the length and difficulty of the operation.

To obtain the former end, the patient's mouth should be thoroughly cleaned and irrigated with antiseptic solution immediately prior to the administration. One hour before the operation, a hundredth of a grain of atropine is given hypodermically, to lessen the flow of saliva.

Anæsthesia is induced in the ordinary way until the patient is unconscious. The administration is then continued through two rubber tubes passed through the nostrils into the pharynx. The mouth is now thoroughly packed with gauze. By this means a free air-way is ensured, while the inhalation of blood and other material from the mouth is prevented (*Fig.* 90). Sometimes it may happen that the nostrils are too small to admit tubes of a sufficiently large size: one may then use an artificial air-way inserted into the pharynx through the mouth, which is then packed off with gauze around it.

FIG. 90.—Showing the administration of an anæsthetic through nasal tubes.

During the preliminary stages of anæsthesia, the patient, supposing him to have a double fracture, may be unable to breathe freely unless the head and shoulders are supported. This difficulty will not grow less as the depth of the anæsthesia increases, and unless the cause and its remedy are known, very serious trouble may arise from impeded respiration. The cause is the displacement of the tongue and the anterior portion of the jaw; and the point to be realized is, that the tongue must be pulled forward and the jaw also. If the jaw only, or the tongue only, be pulled forward, there may be no relief: the traction must be on both. Failing immediate relief from this measure, the patient's head and shoulders must be well raised, when he will usually recommence to breathe. If not, tracheotomy should be performed without delay.

MORTALITY.

Of the 34 patients who had hæmorrhage, 7 died. This mortality is high. At first sight it may seem unduly high; but it must be remembered that, apart from the incident of bleeding, these patients were all suffering from grave

wounds, with other complications superadded to the vascular injuries. In more than one instance the patient already was in a desperate plight from loss of blood by the time that active measures for hæmostasis could be set on foot. *Case* 29 died from sudden and profuse hæmorrhage before assistance could be summoned. He had a wound penetrating the pharynx and tongue, and comminuting the lower jaw, and at the post-mortem examination the left external carotid and right lingual arteries were found both to have been wounded. The fatal hæmorrhage, we thought, had come from the former vessel. In *Case* 26, the patient died from shock within a few hours after ligation of both lingual arteries.

In the five remaining cases which ended fatally, operations had been performed for ligation of the external carotid artery. Of these, *Case* 8 died from recurrence of bleeding from the floor of the mouth, *Case* 30 from cerebral embolism, while *Case* 25 had secondary hæmorrhage from the external carotid at the site of ligature, and succumbed to shock after a second operation for ligation of the common carotid. In *Cases* 14 and 28, operations to secure the external carotid were not persevered with, and the common carotid was tied. Both of these patients died: one from shock, and the other from acute cerebral disorder.

PARTICULARS OF CASES.

Case 1.—Pte. G. C. T., wounded Sept. 15, 1916. Entry wound in region of left angle of mandible. Foreign body lying in right submaxillary region. Lower jaw comminuted at left angle. Tongue greatly swollen and perforated at root.

Sept. 20.—Operation to remove foreign body. Sept. 24.—Hæmorrhage from left side of floor of mouth: stopped by packing. Sept. 25.—Another hæmorrhage; left external carotid ligated. Good recovery.

Case 2.—Corpl. J. L., wounded June 19, 1916. Entry wound in right cheek at upper border of mandible in molar region. Exit wound in corresponding position in left cheek. Bilateral fracture of mandible in both molar regions, with much displacement of anterior fragment.

June 30.—Hæmorrhage from right floor of mouth; arrested by packing, followed by operation for ligation of right external carotid. July 3.—Hæmorrhage recurred: controlled by packing. Calcium lactate given. No further bleeding. Good recovery.

Case 3.—Pte. H. E., wounded July 1, 1916. Entry wound in left cheek at lower bicuspid region. Exit wound at right lower bicuspid region.

July 10.—Hæmorrhage from facial (?) artery; wound packed, and special clamp applied. July 11.—Slight hæmorrhage from left facial (?) artery; wound packed. No recurrence, and good recovery (the source of bleeding was uncertain, probably branches of the facial).

Case 4.—Pte. G. B., wounded Sept. 14, 1916. Entry wound in right lower molar region, and exit wound below and behind left ear. Fracture of mandible in right lower molar region. Perforation of tongue.

Sept. 21.—Hæmorrhage from the tongue; wound packed. No recurrence.

Case 5.—Pte. A. D., wounded by rifle bullet July 12, 1916. Entry wound in right upper lip. No wound of exit.

July 16.—Hæmorrhage from pharynx, with persistent coughing and difficulty in swallowing. July 17.—Operation; tracheotomy; jacket of bullet found lying against right thyroid cartilage. Rectal feeding for following two days. No recurrence of hæmorrhage. Good recovery.

Case 6.—Pte. T. S., wounded June 31, 1916. Extensive wound of lower lip. No exit wound. No foreign body retained. Lower jaw comminuted from right to left bicuspid regions.

July 16.—Two slight hæmorrhages from right side of mouth: wound packed and clamp applied. No recurrence.

Case 7.—Pte. L. E. M., wounded Oct. 7, 1916. Entry wound over angle of right lower jaw. Exit in left lower cuspid region. Comminution extending from left molar to right cuspid region.

Oct. 16.—Severe hæmorrhage from right side of floor of mouth; right external carotid tied. Uneventful recovery.

Case 8.—Pte. A. W., wounded July 5, 1916. Admitted to hospital July 11, suffering from bronchopneumonia. Patient had previously undergone flush amputation of right arm. Severe wound of face. Entry at right upper lip. Fragment of shell lodged just behind right angle of mandible. Fracture of right upper and lower jaws.

July 11.—Hæmorrhage from the mouth. July 17.—Anæsthesia given and foreign body removed; external carotid ligated as a precautionary measure: tracheotomy performed. July 19.—Another slight hæmorrhage. July 22.—Hæmorrhage: clamp applied. Patient died.

Case 9.—Rfmn. J. Q., wounded by rifle bullet Oct. 22, 1916. Entry wound in cheek just above lower right bicuspid region. Fracture of mandible at right bicuspid region.

Nov. 1.—Hæmorrhage from right side of mouth, which was packed. Nov. 9.—Hæmorrhage packed, and clamp applied. Nov. 10.—Slight hæmorrhage. Nov. 19.—Hæmorrhage: right facial artery ligated under novocain. Nov. 21.—Hæmorrhage: right lingual artery ligated under general anæsthetic. Dec. 5.—Hæmorrhage: jaw divided at site of fracture by cutting through callus: inferior dental artery occluded. No further bleeding, and uneventful recovery.

Case 10.—Pte. J. W., wounded by fragment of shell Oct. 22, 1916. Entry, large and lacerated, in right lower first molar region. Comminuted fracture of mandible from right molar to left cuspid region. Laceration of lip, tongue, and sublingual tissues.

Oct. 30.—Hæmorrhage from right ranine artery: bleeding vessel clamped and ligated without anæsthetic. Recovery without further hæmorrhage.

Case 11.—Sapper L., wounded Oct. 7, 1916. Wound of entry in right upper lip. Large piece of shell embedded in right cheek. Alveolar process of upper jaw fractured from right cuspid to left molar region.

Oct. 16.—Hæmorrhage from right facial artery, which ceased as soon as foreign body was removed. Oct. 19.—Second hæmorrhage from left anterior palatine artery: vessel ligated under novocain. No recurrence of hæmorrhage.

Case 12.—A.B. M. M., wounded Nov. 13, 1916. Entry in right lower molar region. Foreign body lodged in right side of tongue. Fracture of mandible in right bicuspid region.

Nov. 19.—Hæmorrhage into the mouth. Nov. 20.—Right lingual artery ligated. Recovery without further hæmorrhage.

Case 13.—Sergt. D. H. P., wounded July 2, 1916. Entry below right lower lip. Exit below angle of right mandible. Comminuted fracture posterior to right lower cuspid.

July 17.—Hæmorrhage from anterior portion of exit wound: operation to tie submental branch of facial artery. No recurrence.

Case 14.—Pte. H. C., wounded July 1, 1916. Entry in right cheek at lower second molar region. Foreign body lying behind angle of left lower jaw. Bilateral fracture of mandible. Extensive laceration of base of tongue (see *Fig.* 73).

July 7.—Foreign body removed. July 8.—Hæmorrhage occurred, which was packed; a second hæmorrhage later in the day. July 13.—Profuse bleeding recurred; an operation to tie the external carotid was not feasible, and the common carotid was ligated. Patient died from shock a few hours later. Post-mortem disclosed bronchopneumonia in both lungs.

Case 15.—Pte. A. S., wounded Sept. 30, 1916. Entry wound in left cheek at region of first molar. Large exit wound at angle of right lower jaw. Bilateral fracture of mandible.

Oct. 9.—Hæmorrhage from branch of right facial; vessel secured in the wound. No recurrence.

Case 16.—Pte. R. J. L., wounded Sept. 13, 1916. Entry wound below centre of lower lip. Exit wound in back of right neck, at level of 6th cervical spine. Paralysis of right arm, due to injury of anterior primary division of the 5th cervical nerve.

Sept. 20.—Hæmorrhage from inferior region; treated by packing. No recurrence.

Case 17.—Pte. F. J., wounded Sept. 14, 1916. Entry wound one inch below left ear. Exit below first right lower molar. Perforation of tongue.

Sept. 21.—Slight hæmorrhage from tongue; controlled by packing. No recurrence.

Case 18.—Sergt. W. L., wounded July 1, 1916. Entry wound below right corner of mouth. Exit just behind left angle of mandible. Bilateral fracture in right cuspid and left third molar regions.

July 20.—Hæmorrhage, probably from left inferior dental at site of fracture; controlled by repeated packings. No recurrence.

Case 19.—Pte. S. D., wounded July 1, 1916. Extensive superficial wound of right side of face and mouth, with comminuted fracture of mandible in right bicuspid region.

July 13.—Hæmorrhage from external wound; artery exposed in wound under local anæsthesia, and ligated. No recurrence.

Fig. 91.—*Case* 21.

Case 20.—Pte. R. C., wounded April 26, 1916. Entry wound right side of face over zygoma. Exit in lower bicuspid region. Right upper jaw fractured.

May 4.—Hæmorrhage from nose; packed. No recurrence.

Case 21.—Pte. A. W., wounded Sept. 27, 1915. Small wound of entrance above left angle of mouth. No exit wound. Fractures of left malar bone, nasal bones, both superior maxillæ, and the lower jaw (in three places), also probably base of skull (***Fig*** 91).

Nov. 12.—Hæmorrhage from nose and into nasopharynx; nostrils packed. Numerous recurrences from Dec. 2 to Dec. 16. Evacuated to England at patient's own request before we were certain that the recurrence of bleeding was no longer possible.

Case 22.—Pte. H. L., wounded Oct. 12, 1915. Entry wound at left corner of mouth. Exit in right lower molar region. Comminution of mandible from one molar region to the other. Laceration and swelling of tongue (***Fig*** 92).

Oct. 20.—Hæmorrhage from floor of mouth; right external carotid tied. Good recovery.

Case 23.—Pte. F. D., wounded March 15, 1916. Entry wound left corner of mouth. Exit at angle of right mandible. Perforation of tongue.

March 22.—Hæmorrhage from root of tongue: left external carotid tied, which did not stop the bleeding: repeated packing, and application of clamp, checked hæmorrhage. April 9.—Secondary hæmorrhage from left external carotid at place of ligature; common carotid and internal carotid ligated. Operation followed by hemiplegia.

Case 24.—Pte. J. W., wounded July 3, 1916. Entry wound one inch to right of nose. Exit wound in front of lobe of left ear. Hard palate perforated.

July 8.—Bleeding from nose: nostrils packed. No recurrence.

Fig. 92.—*Case* 22.

Case 25.—Pte. P. L., wounded Sept. 15, 1916. Entry wound over angle of right lower jaw. Exit just below angle of left lower jaw. Right mandible fractured at angle. Pharynx perforated.

Sept. 19.—Hæmorrhage, source of bleeding uncertain; wound too far back to be packed: rectal feeding employed. Sept. 25.—Hæmorrhage: right external carotid ligated. Oct. 4.—Secondary hæmorrhage from external carotid at site of ligature: common carotid tied. Left hemiplegia developed, and patient died two days later.

Case 26.—Pte. G. G., wounded July 13, 1916. Entry wound in left bicuspid region. Exit in right cheek, exposing alveolar processes of upper and lower jaw. Right side of mandible destroyed in bicuspid and molar region, and comminuted fracture present in left bicuspid region.

July 19.—Hæmorrhage: both lingual arteries tied in the floor of the mouth; the external wound was sufficiently extensive to permit this. Patient died of shock a few hours later.

Case 27.—Capt. W. H. S., wounded Sept. 15, 1916. Projectile entered left scapular region, emerged from left neck, and struck the lower margin of the mandible on the left side one inch in front of the angle, causing an extensive wound of the lower face from the point of entry to the middle of the lower lip. Lower jaw completely destroyed from left molar region to right bicuspid region. Much laceration of the sublingual tissues.

Sept. 28.—Hæmorrhage from sublingual region: packed. Several recurrences occurred, which were successfully treated by packing.

Case 28.—Co. Sergt.-Major H. B., wounded July 29, 1916. Entry wound in left face at angle of mandible. Large wound of exit in corresponding region of right side. Bilateral fracture of lower jaw at both angles. Tongue lacerated and swollen (see *Fig.* 74).

Aug. 7.—Hæmorrhage from left side of mouth: operation for its control: ligation of common carotid necessary; no direct cerebral complications. Aug. 8.—Hæmorrhage from mouth: right external carotid ligated. Patient died after a few hours.

Case 29.—Capt. E., wounded Nov. 13, 1916. Entry wound in left mastoid region. Large exit wound extending from right corner of mouth along lower border of right mandible. Laceration and swelling of tongue.

Nov. 21.—Severe hæmorrhage occurred, and patient died almost immediately.

Case 30.—Pte. L. D., wounded Oct. 14, 1916. Entry wound at middle of chin. Fragment of shell lodged subcutaneously in left side of neck over sterno-mastoid. A fragment of bone formed a secondary projectile, which penetrated deeply into the floor of the mouth. Fracture of mandible at symphysis.

Oct. 23.—Hæmorrhage from floor of mouth. Oct. 25.—Right external carotid tied. Oct. 27.—Left hemiplegia developed suddenly, with dilatation of left pupil and laryngeal paralysis. Oct. 30.—Patient died.

Post-mortem Examination.—Embolism of right middle cerebral artery, with softening of brain, most marked in right internal capsule. The stump of the external carotid was filled with firm clot, which, however, extended down into the common carotid. There was a fragment of bone lodged against and displacing backward both lingual arteries, which were partially torn across. Multiple foci of suppuration were present in both lungs (inhalation pneumonia).

Fig. 93.—*Case* 31.

Case 31.—Pte. H. L. M., wounded Aug. 5, 1916. One large lacerated wound of lower lip, chin, and sublingual regions, with comminuted fracture extending from one molar region to the other (*Fig* 93).

Aug. 16. — Hæmorrhage; lingual artery ligated directly at bleeding point. No recurrence.

Case 32.—Lance-Corpl. J. L., wounded Oct. 23, 1916. Entry wound at edge of left upper lip. Large exit below and behind right angle of mandible, exposing the external carotid artery. Right lower jaw fractured at the angle.

Nov. 4.—Severe hæmorrhage from right facial artery at a point half an inch from its origin from the external carotid; vessel ligated at bleeding point; right lingual also ligated. No further hæmorrhage.

Case 33.—Pte. W. M. G., wounded Oct. 13, 1916. Entry wound in left lower molar region. Exit at left corner of mouth, where there was extensive laceration. Comminution of left lower jaw from molar to cuspid region.

Oct. 18.—Hæmorrhage from branch of left facial artery; treated by packing.

A REPORT ON ORAL AND PLASTIC SURGERY AND ON PROSTHETIC APPLIANCES.

By Major A. C. VALADIER, C.M.G., R.A.M.C. (T.H.C.),
and Captain H. LAWSON WHALE, R.A.M.C. (T.)

MAJOR VALADIER'S REPORT.

Recent medical literature has contained many monographs on the treatment of fractured jaws. Some of these are remarkable for their length rather than for their addition to our knowledge of the subject. Others are richer in scientific interest, but as contributions to war surgery their technical value is discounted by the point of view adopted by the authors, for they seem to approach the subject as if they were dealing with fractures as they occur in civil practice. This attitude not only fails to help those who may wish to study the subject, but may mislead them: for the treatment of jaws fractured in war is very different from that of injuries received in peace-time: and only those who have handled a large number of cases can give reliable guidance.

In July, 1916, an English medical journal published an article wherein the author stated that "The great number of jaws fractured in this war could be so treated that the patients should be back in the firing line in five or six weeks." I can come to but one conclusion, which the photographs here published corroborate—namely, that the writer has no experience of what we in France call serious fractures of the jaws due to gunshot wounds. For over two years I have given unremitting attention to facial injuries and fractured jaws, and have obtained in the majority of cases more than good results; but in citing some of these, and giving reasons for the various measures adopted, I will not attempt to formulate laws. For extended experience in this kind of work has shown that each case must be treated as one *sui generis*. The plastic side of the work is most important. Mutually interdependent are the oral and plastic work, and the surgeons responsible for each of these must work in co-operation, if good results are to be expected.

In July, 1916, I was fortunate in being joined by Captain H. Lawson Whale, and by mutual consideration we have obtained results which have at times exceeded our expectations. Doubtless some of our proceedings will seem unorthodox, but the results will bear examination, even when carried out on principles as revolutionary as the following:—

1. All remaining teeth should be preserved as far as possible; even old roots may be kept and filled, and may prove most useful in providing support for interdental splints. The secret of orthodontia lies in obtaining proper occlusion of teeth. To obtain a *point d'appui* for interdental apparatus is difficult in the English soldier's mouth, because his teeth are generally poor in quality and few in number. If the oral surgeon removes all roots and

stumps, and some teeth, he is indeed sacrificing his only asset. This does not necessarily mean that after teeth and roots have been used for purposes of support, they should not be extracted at a later date; nor does it mean that teeth directly in the line of fracture should not be removed. The view here expressed differs radically from that of those who would extract all roots, and the teeth on either side of the fracture. Discretion must, in fact, be exercised by the surgeon: no cast-iron rule can be observed, and if one permits oneself to be guided by narrow views, 'failure' will be the result in the majority of cases.

2. In extensive injuries of the face, the wound should be closed as soon as possible: if necessary, before placing the jaw in position. Dr. C. Powers, of the American Ambulance at Paris, recently remarked that if an emergency case of large facial wound were brought to him in peace-time, and he neglected or postponed the immediate approximation of the parts, he would later on be the defendant in a civil action-at-law. Why, then, delay in war surgery? The precise moment at which to close the wound cannot be laid down in hours

Fig. 94.

Fig. 95

or days, since of course it varies in different cases; but in general terms it may be said that, however dirty the wound, it should be closed in a few days, and long before it is thoroughly clean. In fact, an official French medical order exists, demanding that all such wounds be closed as soon as possible after having been thoroughly cleaned with ether. Perfect asepsis is in any case unattainable, since the wound is usually compound into the mouth. I have been throughout the hospitals in France, and found many faces shattered beyond any chance of satisfactory correction: large flaps hopelessly inverted, cicatrized, and almost keloidal. It should be remembered that a flap produced by laceration will quickly shrink in size, just as does one made by a surgeon in plastic work: a good reason for sewing up early.

As soon as, or even before, the palatal arch has been built up, or the jaw put into position, two rows of stitches are inserted. The deep layers, of heavy catgut, embrace fascial and muscular strata; each stitch is put in at a generous distance from the free edge, and may if desired perforate the mouth; in the latter case it is sometimes convenient to tie the knots inside

the mouth. The superficial layer, of stout salmon-gut, approximates the skin —partially in most cases, rarely completely. This layer may be reinforced by wide tension-sutures tied over vulcanite buttons (*Figs.* 94 and 95). Drainage of the mouth is generally required, and should be obtained by a median submaxillary stab-wound into which a rubber tube is inserted. It must be emphasized that these superficial stitches (other than tension stitches over buttons) are expected to break down. But while they hold, they keep the skin edges together sufficiently to allow the deeper structures to granulate—sometimes completely, sometimes leaving a buccal fistula for subsequent closure. Where there has been a loss of tissue in the upper or lower lip, however, it is unwise to draw the edges together: experience has taught me to recommend and practise the formation of an artificial hare-lip above and below, as seen in *Fig.* 116 C.

3. When, as often happens, the initial closure of soft parts precedes the orthodontal correction, there is a strong tendency for the soft parts to shrink with cicatrization. This renders the work on the jaw itself difficult or impossible, and to prevent it, interdental appliances to which wire has been attached for the grasping of modelling compound (stents) must be inserted, and increased as necessary, to preserve the contour (*Fig.* 105).

4. Under the heading (2) above, it has already been explained that the superficial stitches are expected to break down; but this should not occur too soon. To take an exaggerated instance: if the salmon-gut sutures break away a few hours after insertion, they have not had time to serve their purpose as a scaffolding, and indeed might well have been omitted. The avoidance of such happenings suggests a fourth general principle: that it is unwise to attempt to bring the parts into unnecessarily perfect position at the outset, lest the tension on the stitches should cause them to break down.

In regard to the prosthetic appliances used for the reduction of fractures of the jaw, it is difficult to lay down a law, or to express a preference for any one in particular. Cases differ so much, that the decision in each instance must always remain with the operator. I can but indicate some of the appliances I have used for certain patients herein mentioned, fully realizing that another surgeon might have treated these cases with as good results, while employing very different appliances. My endeavour has been to keep these as simple as possible, avoiding unnecessarily complicated methods.

Various ways of treating the many cases of trismus with which we come in contact have been brought forward during this war. Complicated and expensive appliances have been recommended, which in my judgement are uncalled for and unnecessary, for I have never yet had a case of false trismus which did not respond to treatment by plain wooden wedges within five or six days at the utmost; the wedges are inserted between the teeth, larger sizes being provided progressively.

The following illustrations of splints (*Figs.* 96–112) are such as I have used from time to time and have found most efficient. Some of them are original, and others I have seen in the different hospitals I have visited. If I omit to give due credit to the originator of any of these appliances, it is not from any desire to withhold it, but from ignorance of the real source.

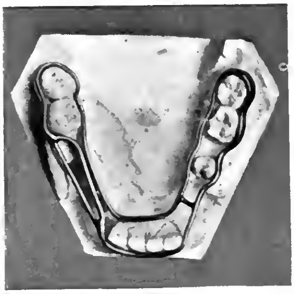




FIG. 96. FIG. 97. FIG. 98.

Fig. 96 shows an appliance used in my wards for cleaning wounds by means of boiled water. The patients have nicknamed it the 'Fire engine.' A petrol tin is placed upon a platform with rubber wheels, a bicycle-pump attached alongside for the purpose of obtaining pressure, and a pressure-gauge is added on the top of the tank. This is wheeled about from bed to bed by the sisters. Any solution can be used. It is simply a carrier, and saves a great deal of time.

Fig. 97.—A form of 'Hammond' splint very often used.

Fig. 98.—A simplified 'Kazanjian' spring and support made to keep up the denture when the palate has been shot away. This is a pre-war invention of Dr. Kazanjian (Harvard unit).

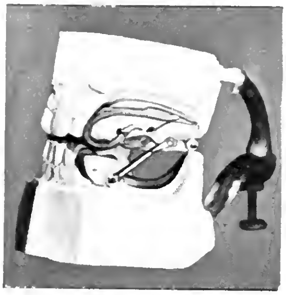


FIG. 99. FIG. 100. FIG. 101.

Fig. 99.—A splint used to keep the inferior maxilla in position when the fracture is posterior to the teeth.

Figs. 100 and 101.—Pope's splint, for use after loss of the condyle; I take this opportunity of recommending this ingenious apparatus.


FIG. 102. FIG. 103.

Fig. 102.—The 'Villain' splint.

Fig. 103.—Emergency splints.

Fig. 104.

Fig. 105.

Fig. 106.

Fig. 104.—Jack-screw pushing the jaw into position.

Fig. 105.—An obturator for the superior maxilla, showing wiring vulcanized into it for the purpose of adding stents, and thus obtaining proper lines of contour for the face.

Fig. 107.

Fig. 108.

Fig. 109.

Figs. 106-8.—Show a splint for the purpose of building out the chin. This case was made for the patient in *Fig.* 109. It is constructed in four sections.

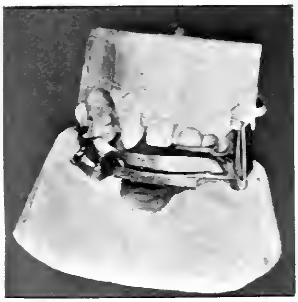


Fig. 110.

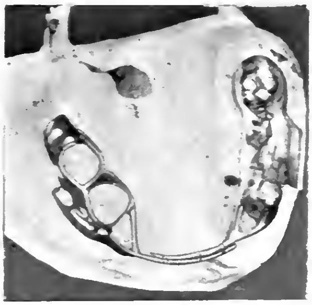


Fig. 111.

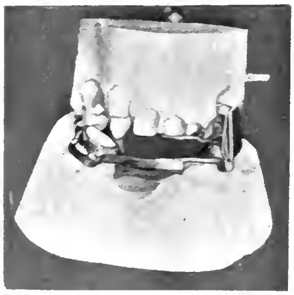


Fig. 112.

Figs. 110, 111, 112.—A flange and bridge splint, made for a patient having a fracture posterior to the right angle of the inferior maxilla: loss of bone from the second right to the second left bicuspid. The lower removable bridge maintained the line of arch in position, permitting the fracture posterior to the angle to unite. The flange held the left side of the jaw in position and removed the strain on the right side.

Some points of clinical interest to the general surgeon may be mentioned. The chief complications and sequelæ of these extensive facial injuries are the following :—

1. *Secondary Hæmorrhage.*—A slight oozing, or venous flow of one or two ounces, is fairly common. But out of 1010 cases, it has been necessary to tie an artery in its continuity through a fresh incision in only 11. The loss of tissue is often so extensive, or the track made by the projectile so deep, that it is usually impossible to acquit of responsibility for the hæmorrhage any branch of the external carotid, except the superior thyroid, posterior auricular, and occipital. Accordingly, it has become Captain Whale's routine practice, in cases of severe bleeding, to tie at once the external carotid just above the origin of the superior thyroid. The free collateral circulation, which enables the surgeon to take such liberties with the soft parts about the head and neck, also occasionally inconveniences him : thus, a unilateral wound will sometimes bleed a few days after tying the external carotid. With us, however, such hæmorrhages have never been serious enough to require further surgical interference.

2. *Tracheotomy.*—This has only been done in 2 of the 1010 cases. In one emergency it was necessary to perform laryngotomy under novocain anæsthesia (Captain Whale).

3. *Lung Complications.*—The large majority of the fractures are compound both into the mouth and outward, and only reach us two or three days after infliction, in a very fœtid state. The relative rarity of lung complications is therefore striking, and reflects great credit upon the nursing. Seven patients have died of pneumonia. The autopsies show that the lesion is generally of an inhalation type, often with massive abscess of the lung, and gangrene (Captain Greenfield). Only one rib-resection for empyema has been made (Captain Whale). For two years I have been cleaning all jaw injuries with boiled water, avoiding antiseptics as much as possible, for I believe them to be irritants, harmful to mucous surfaces.

4. *Infection of Adjacent Structures.*—There has been one case of erysipelas, and one of sinusitis (maxillary antrum, cured by operation—Captain Whale). Two patients have had quinsies, each, however, having been subject to this complaint before the war. The condition is sometimes difficult to deal with in a patient with a fractured jaw. If access to the tonsillar region is cramped by a false trismus, the wooden wedge which I use overcomes the difficulty, provided the diagnosis is so early that the quinsy can wait forty-eight hours while the wedge is doing its work.

5. *Grave Local and General Sepsis.*—One case died of streptococcal septicæmia, one of septic meningitis, and one of general pyæmia; the last had pus in his heart walls, and abscesses in most of his abdominal organs, including the jejunum and mesentery (Captain Greenfield). Two patients died of mediastinitis, which spread from a retropharyngeal abscess in the track of the missile ; in one of these, implication of the vagus and the sympathetic in the purulent track was diagnosed clinically, and confirmed post mortem (Captain Whale and Captain Greenfield).

Of 1010 cases of jaw and facial injuries, I would point out the small number of deaths (27) ; of these, 7 were beyond saving on their arrival.

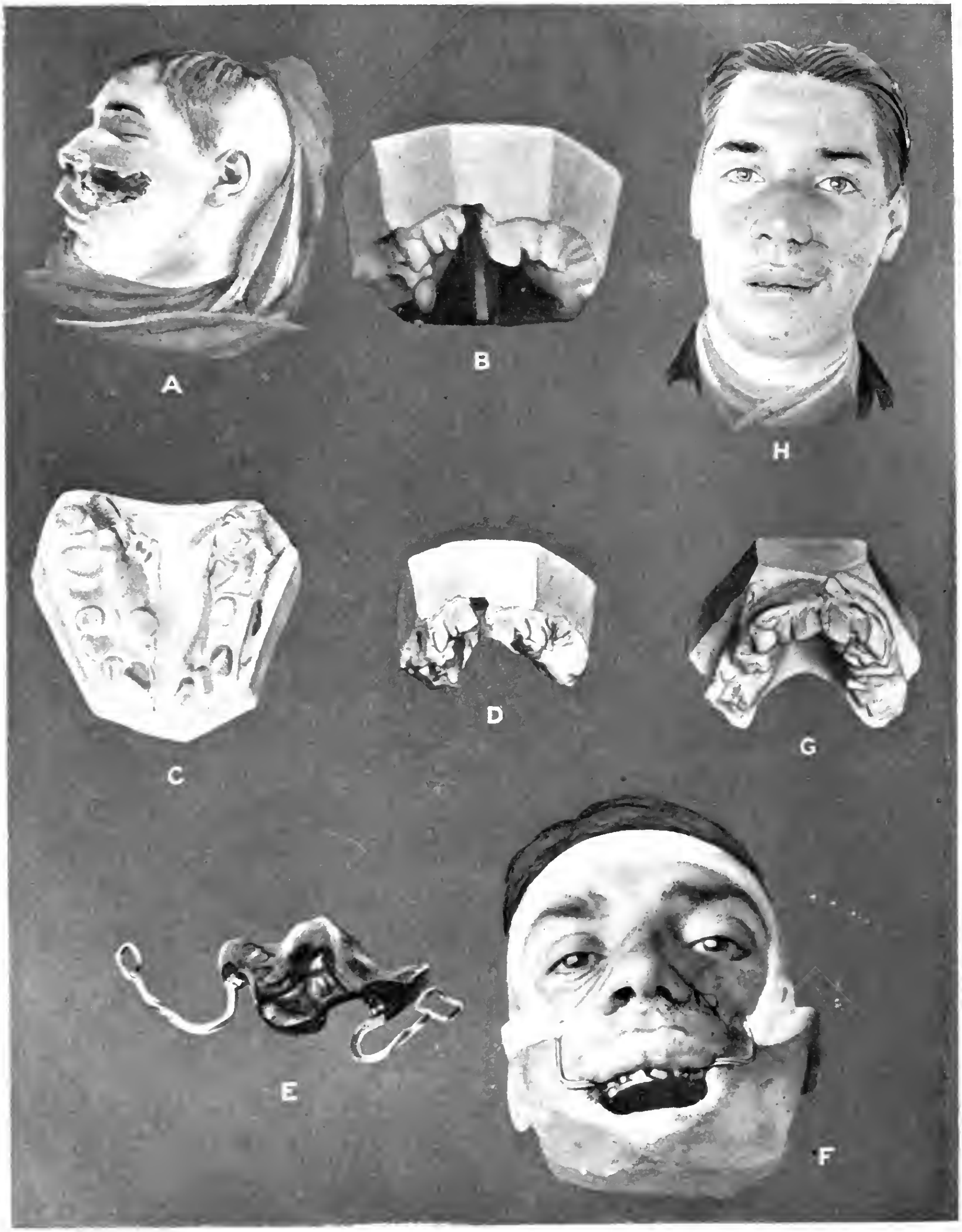
The following photographs (*Figs*. 115–126) illustrate twelve cases, showing the gradual progress made from time to time. They are accompanied by clinical notes abstracted from the case records. Realizing that the photographs obtained did not clearly demonstrate the seriousness or depth of wounds, I decided on Jan. 1, 1917, to obtain them stereoscopically, and I am giving two of these here, simply for the purpose of showing their value. (*Figs*. 113, 114). They should be examined through stereoscopic lenses.

FIG. 113.

FIG. 114

NOTES AND ILLUSTRATIONS FROM PHOTOGRAPHS OF TWELVE TYPICAL CASES.

FIG. 115.—*Case* 1. Pte. R. Gunshot wound. The projectile perforated the antrum and shattered the superior maxilla. (Major Valadier operating.)

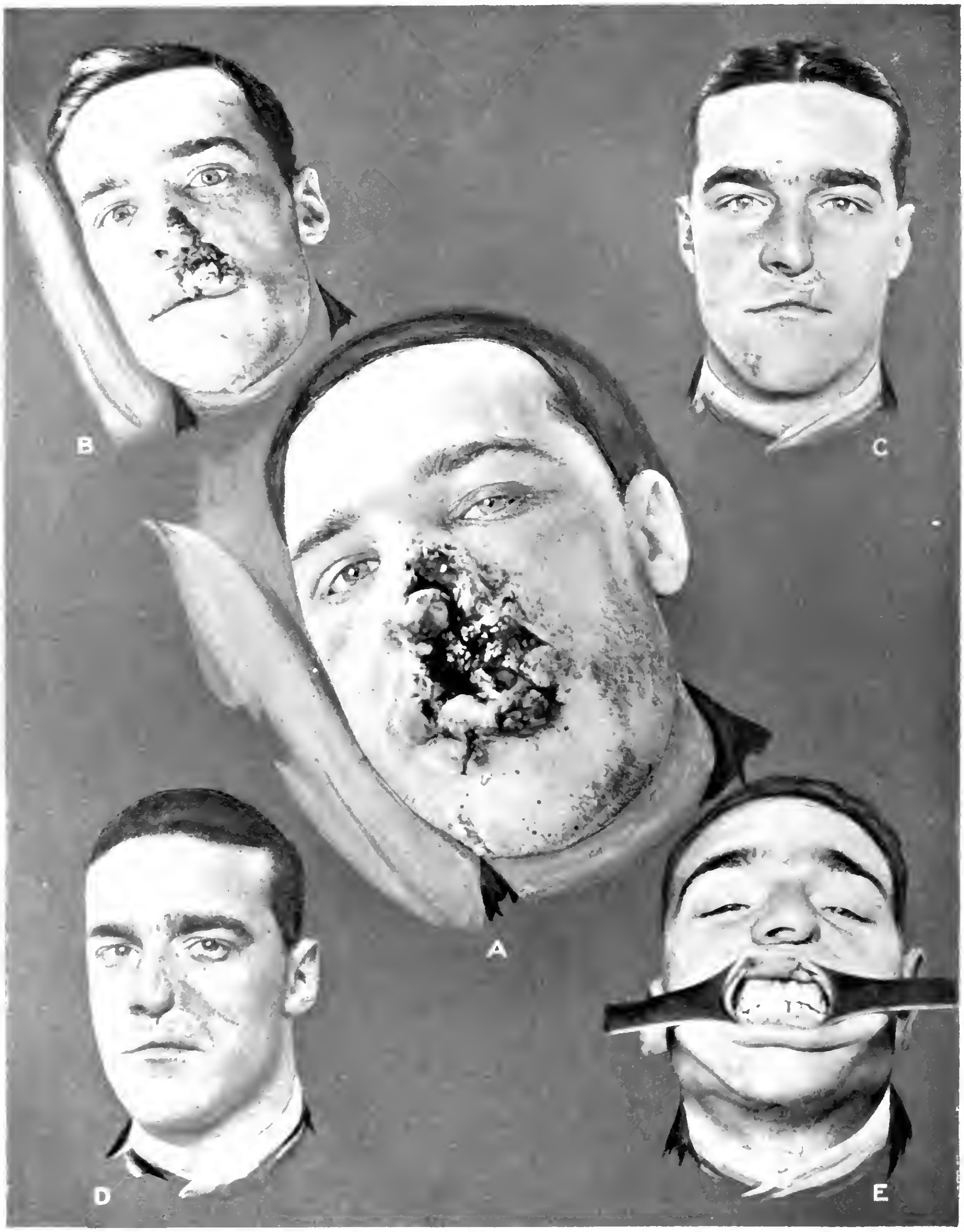


A. Patient as he arrived; B. C. D. Models of the superior maxillæ, showing the left one much below the right; E. Splint used to pull the maxilla into position; F. Splint in position; G. Maxillæ in position; H. As evacuated to England.

FIG. 116.—*Case* 2. Pte. J. S. Explosive bullet wound. The inferior maxilla was shattered: the symphysis is missing: one right and left molar, one right premolar root, and one left premolar are the only existing teeth left in the mouth. Angle bands and bar were immediately inserted to keep the line of the arch, and the wound was closed, an artificial hare-lip being formed. (Major Valadier operating six times, and Colonel Fullerton once.)

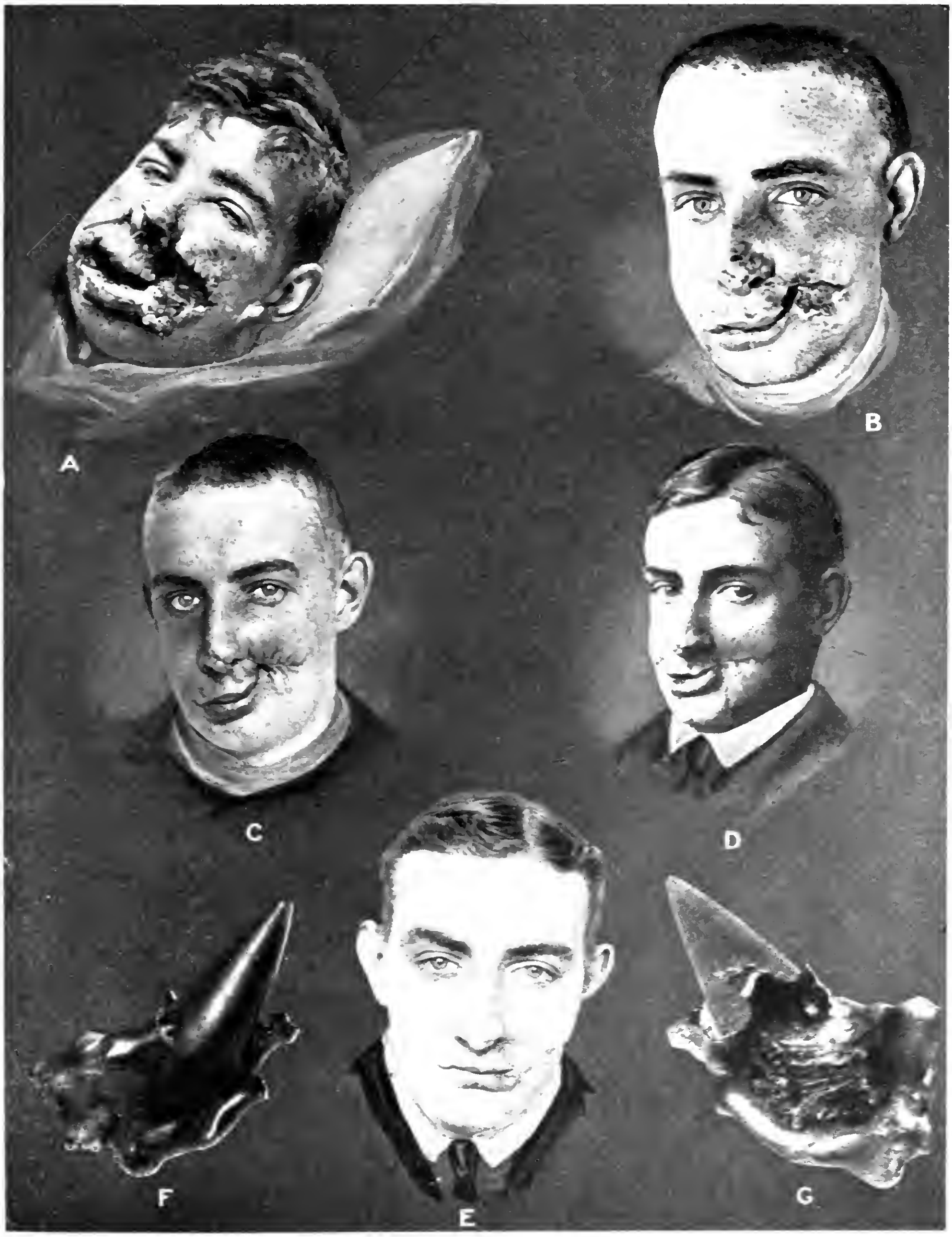
A. Patient as he arrived; B. Three weeks after arrival; C. Eight weeks after arrival. At this stage the Angle bands and bar were removed and a simple vulcanite splint was inserted, as seen in D. E. F. Hare-lip corrected. The mouth not being very straight, and considerable cicatricial tissue existing, this was re-corrected four weeks later, and then teeth were inserted: the result is seen in G and H; I. Skiagram showing present union of bone.

FIG. 117.– *Case* 3. Pte. R. W. S. Shell wound, whizz-bang. Fracture of the inferior and superior maxillæ. The superior maxilla was ligatured into position by means of silk floss, as well as the lower jaw, and the wound was immediately closed as far as possible. (Major Valadier operating; Captain Whale assisting.)



A. Patient as he arrived; B. Four weeks later; C. Upper lip corrected; D. Flap made in anticipation of forming alæ of nose; E. Present condition of the mouth after teeth were inserted.

FIG. 118.—*Case* 4. Pte. S. Explosive bullet. The inferior maxilla was fractured, and an entire portion of the palate gone: both antra were open and in a most gangrenous condition. All the upper teeth were gone save one molar on each tuberosity, dangling in the mouth: both of these were ligatured into position, and in six weeks both tuberosities and teeth became absolutely sound. The wound was closed at the same time. (Major Valadier operating: Captain Whale assisting.)

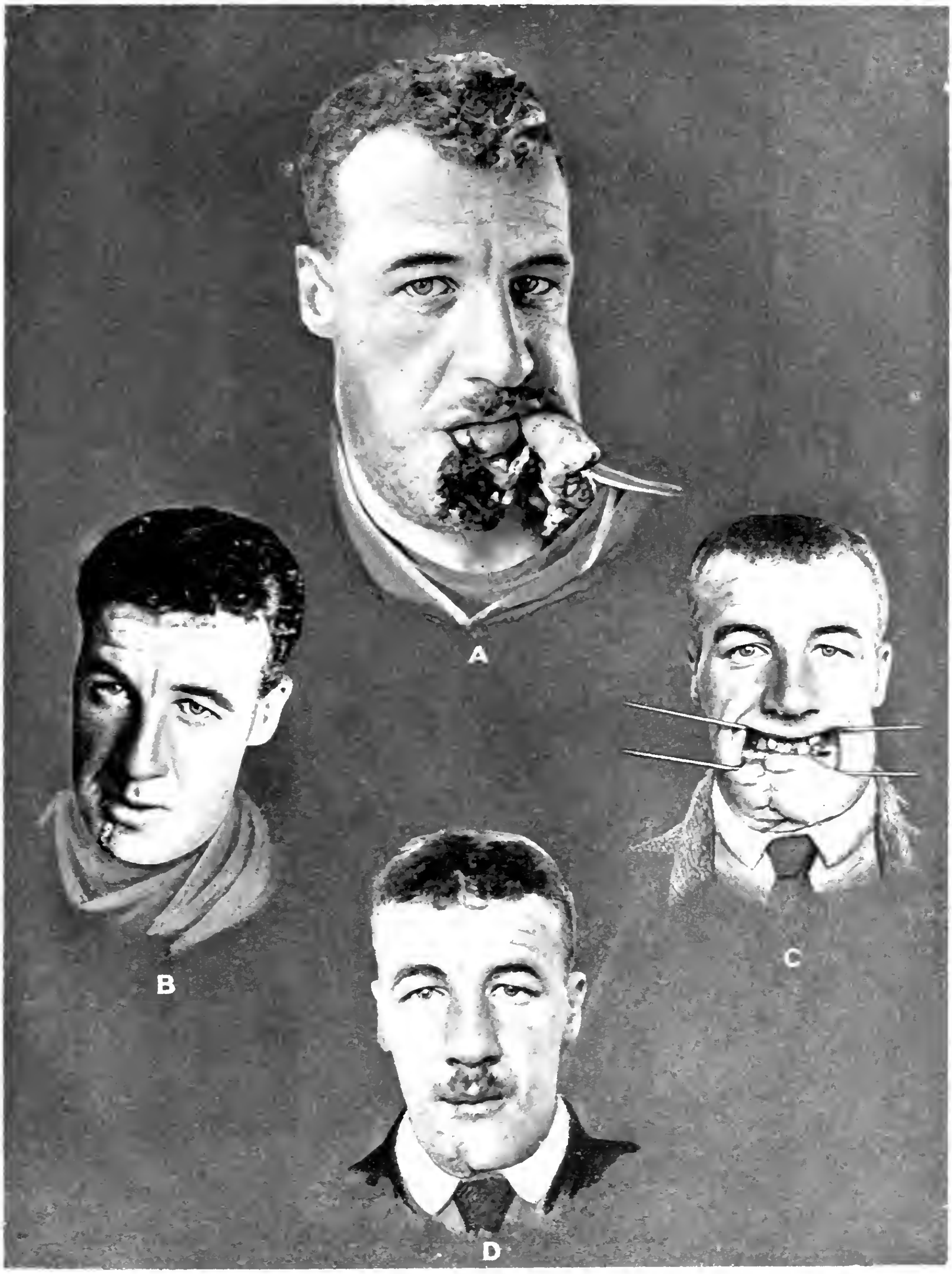


A. Patient as he arrived: B. Six weeks later: C. Twelve weeks later: scar tissue removed and the cheek freed: D. Fifteen weeks later: E. Five months later: present condition: F. G. Explosive bullet removed from the maxillary sinus. It had shattered both superior maxillæ.

FIG. 119.—*Case* 5. Pte. J. P. Shell wound, high-explosive. Fracture of the inferior and superior maxillæ, with extensive facial wound. (Major Valadier operating; Captain Whale assisting.)

A. On admission; B. Ten days later. Immediate suturing: the jaws held in position by means of silk ligatures; C. Five weeks later; D. Silk ligatures removed and dentures inserted; E, F. Scar tissue removed; present appearance five months after admission.

FIG. 120.—*Case 6.* L.-Corpl. W. B. High-explosive shell wound. (Major Valadier operating: Captain Whale assisting.)

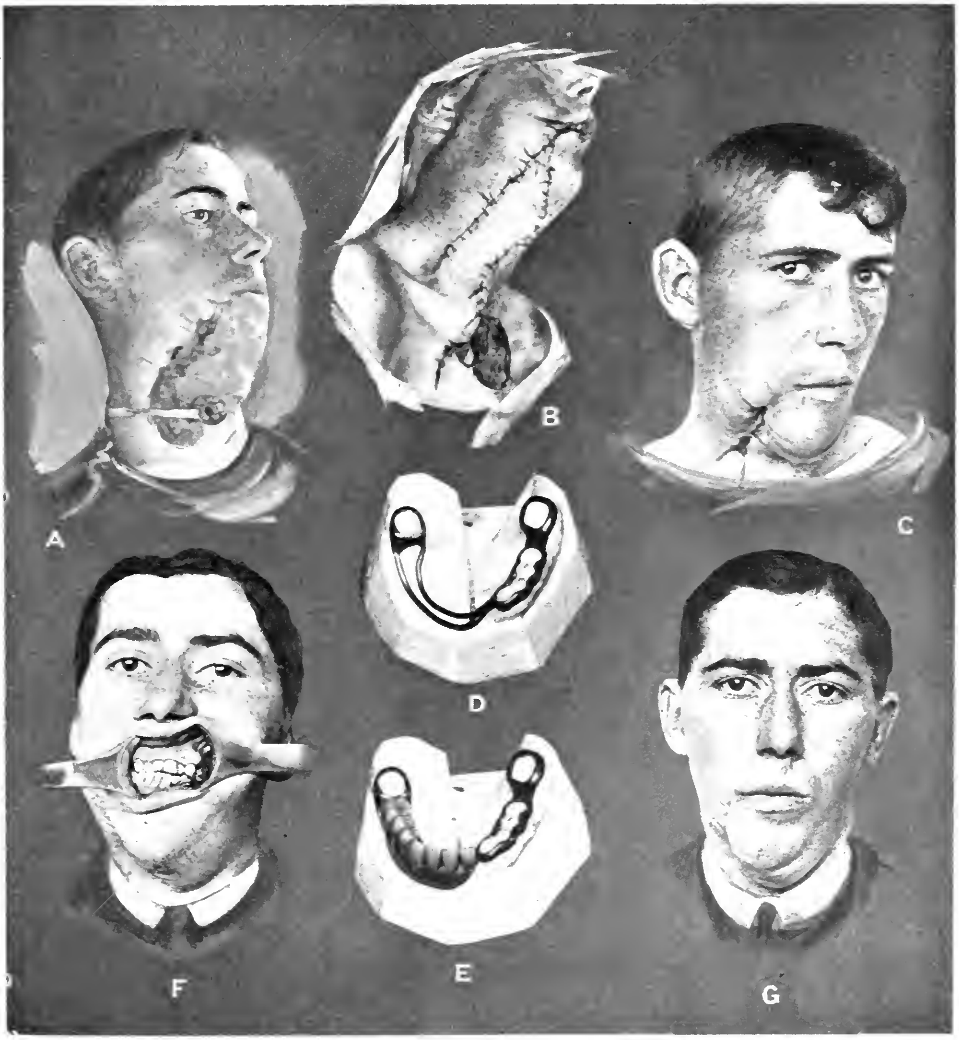


A. Patient as he arrived. The inferior maxilla was badly shattered, but healthy mucosa was found on each separate piece of bone. Therefore in this case, although I am not in favour of wiring, the bones were fixed in position by fine silver wire, and Angle bands and bar were added to preserve the line of the arch. The wound was immediately closed: B. Three weeks after admission: C. Shows the Angle bands and bar in position: D. As evacuated to England, by which time the wires had been removed, with a certain amount of necrosed bone. Two centrals were also removed, as they had accomplished their purpose of support.

FIG. 121.—*Case* 7. Pte. McL. High-explosive shell wound. The superior maxilla was carried away, leaving a molar on each tuberosity; these were very loose, but it was decided to tie them into position. The inferior maxilla was fractured, right and left, posterior to the premolars. Angle bands and bar were inserted. Six weeks later, the upper teeth and tuberosity were perfectly sound. (This plan I have followed many times without a failure.) The inferior maxilla united. (Major Valadier operating.)

A. Patient as he arrived: B. Eight weeks later, with jack-screw splint to prevent contraction as seen in C: D. The splint by itself. The nose and face being depressed as seen in E, I decided to make an aluminium head-casque as in F, and a splint for the upper jaw, as seen in G, H, I; K, Shows these appliances in position: L. A side view showing the difference compared with E. At this stage, owing to pressure of work and necessity of beds for new cases, this patient was evacuated to England.

FIG. 122.—*Case* 8. Pte. P. Gunshot wound of jaw, with extensive comminution. The patient was admitted wearing a tracheotomy tube, and with a gangrenous chasm occupying the whole right anterior triangle of the neck. (Captain Whale operating; Major Valadier assisting.)



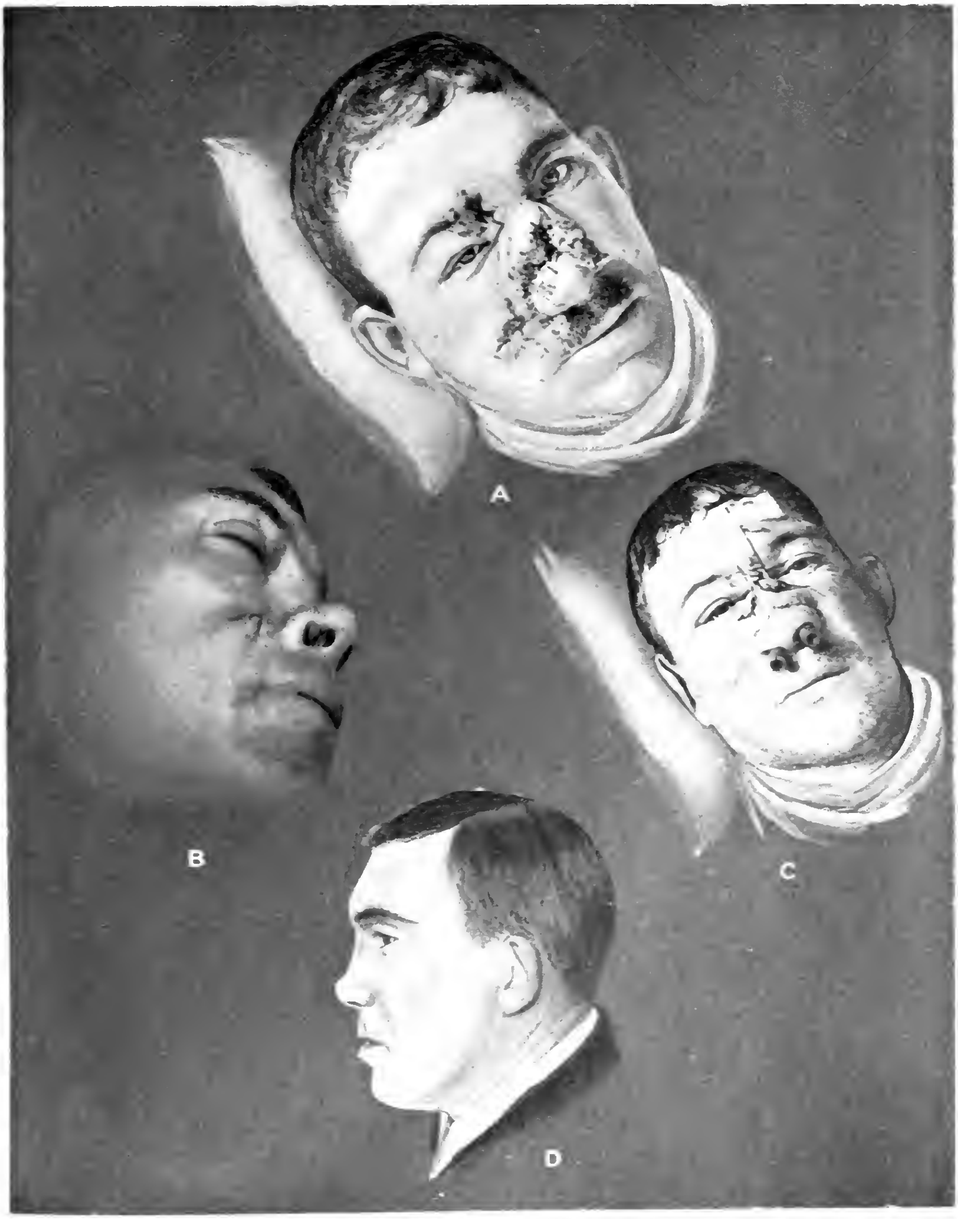
A. Appearance on admission: B. Fifteen days later. Shows a pedicled flap turned up from the chest: C. Four days later. The upper third of the flap, infected by saliva, has sloughed: D. Shows a wire trough fixed to the teeth on the sound side: E. The same with teeth to raise the level of the gap in the jaw; F. Five weeks after admission. Denture fixed: G. Present condition. The keloid scar is at present stretching.

*

FIG. 123. *Case* 9. Pte. W. Gunshot wound, destroying the whole nose below the nasal bones. (Captain Whale operating; Major Valadier assisting.)

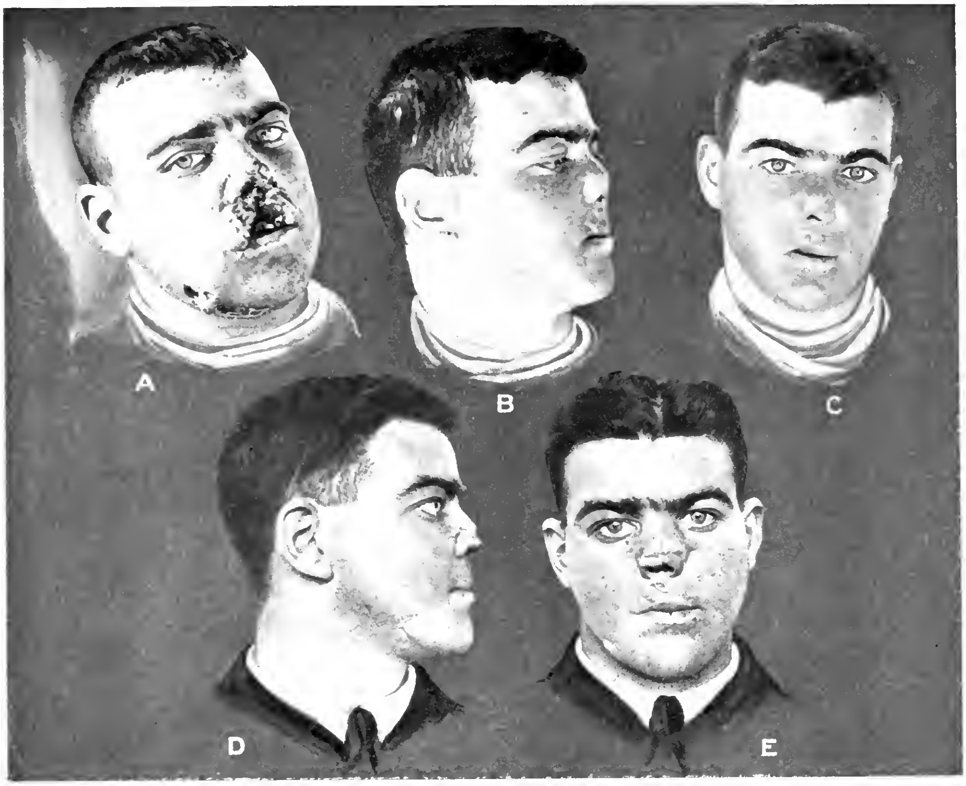
A, Appearance on admission. Vulcanite splints were made to prevent adhesions to the septum; B, Six weeks later. Piece of the 8th costal cartilage beneath the frontal periosteum; C, The same, profile view; D, Nine weeks later. Shows a frontal flap, containing cartilage, turned down; E, F, Shaping the nose.

FIG. 124.—*Case* 10. Corpl. E. Gunshot wound of the nose. The bony and soft parts between the nasal bones and the lobule were shot away. (Captain Whale operating: Major Valadier assisting.)



A. Appearance on admission. The next day the patient developed scarlet fever: B. After cicatrization eight weeks later: C. Operation three months after admission, flaps to fill the gap being taken from the skin over the nasal bones. The bridge was re-formed from the septum nasi: D. Appearance on discharge to England five months after admission.

FIG. 125. *Case* 11. Pte. W. Gunshot wound, destroying the upper lip and premaxilla. (Captain Whale operating: Major Valadier assisting.)



A, Appearance on admission; B, C, Five weeks later. A new lip was formed, but the cicatricial tissue seen forbade re-interference to create columella and tip of nose, which I am now making from the forearm; D, E, Flaps from cheek to form the tip (not sufficient).

FIG. 126.—*Case* 12. Pte. A. Gunshot wound, destroying the right mandible, chin, and hyoid region. (Captain Whale operating: Major Valadier assisting.)

A Appearance on admission; B, Six weeks later, after a plastic operation; C, Present condition.

CAPTAIN WHALE'S REPORT.

Major Valadier has kindly asked me to add my observations to his own more important paper. He had been doing this work for eighteen months before I joined him. Up to this time my experience was limited to some patients treated jointly by Major Valadier and myself in Boulogne in the first three months of the war, before the existence of a special department, and subsequently in England to a few other cases to which I had access only after the wounds had completely healed; so that my experience of facial surgery is much less than his. I can, however, after seven months' collaboration, fully endorse the principles he has laid down, especially as regards the early closure of wounds.

At the primary operation, all tissues not hopelessly dead should be conserved. Especially does this apply to:—

1. Bone and mucous membrane. Preservation of these structures may obviate the necessity of transplantations in the case of bone, and of extensive sliding flaps in the case of mucosa, the loss of viability of either of these never being certain.

2. Parts of the face which are difficult to build up artificially, such as the columella or alar margin of the nose (see *Fig.* 124). At the beginning of the war, Major Valadier and I sacrificed pieces of tissue which we should nowadays retain. He has already mentioned that when, as is usual, the mucosa of either lip has been sewn out of its correct position to any accessible spot in order to keep it alive, it only remains thereafter to follow the general principles of hare-lip operations. We have, however, encountered one important difference. If an operation on a congenital hare-lip is for any reason unsatisfactory, the surgeon operates anew as if on a fresh case, the soft, elastic tissues, especially in an infant, permitting of this. But in our work we are dealing with inelastic and sometimes avascular cicatricial tissue, less tolerant of repeated interference. So that: (1) Provided we have obtained a good vermilion border—if the parts break down, or the cosmetic result is imperfect, it is better to let the lip heal in so far as it will, and later to perform minor operations: (2) A destroyed columella usually cannot be reconstructed by the convenient flap from the upper lip, since the wound has as a rule involved this lip also (see *Fig.* 125 B). Having restored the lip, it is unwise to disturb it again; and the columella must be made from the face by the French method, or better, from a hairless part of the arm or forearm by the Italian method.

Before finally and completely covering in a loss of skin in the region of the jaw, the buccal cavity should have been shut off, by nature's granulations, or the surgeon's stitches, or both. If this has not occurred, then, if the gap be closed by undercutting and sliding adjacent skin, a troublesome salivary fistula results. Major Valadier has been very successful in dealing with such cases by sutures of heavy catgut which embrace the deep structures only and do not reach either to the mouth or to the skin surface. But if, in order to close such a gap, it has been necessary to swing up a long pedicled flap from the thoracic wall, the evil results of an unclosed communication with the mouth are much more marked. The

distal end of the flap may slough away; and although the proximal part heals, its healing is attended by gross keloid formation, owing to the constant re-infection (see *Fig.* 122 C).

Whoever practises plastic facial work would do well not to adhere implicitly to text-book directions; thus :—

1. The time which should elapse between successive steps of surgical procedure can only be ascertained by experience. In general it may be said that the primary closure of the wound is undertaken too late, and all subsequent stages too early. In particular, the pedicles of transplanted flaps can rarely be divided safely after ten or fourteen days, as often stated; three weeks is as a rule a minimum.

2. The margin allowed for shrinkage of flaps is commonly given as one-sixth of the area. In our experience, one-third is more accurate; that is, a piece of soft tissue should be cut one-third larger than it is ultimately intended to be. It must be remembered that the flap continues to shrink for many weeks, and in all diameters. Thus, a nose made from the frontal tissues shrinks upwards towards its pedicle, so as to lie too high on the face; and the piece fashioned for the columella may shrink until it is not long enough to reach the lip (see *Fig.* 123 D).

In making a nose from a forehead flap containing a previously implanted rib cartilage, it is debatable whether the latter should be grafted superficial or deep to the periosteum. We have succeeded with both methods.

For building up smaller gaps in the nasal bridge after a subtotal loss of the nose, it is useful to swing up a vertical strip from the cut anterior edge of the cartilaginous septum; this strip remains attached to the septum at its upper end (see *Fig.* 124 C).

The later stages in the fashioning of a nose by the Indian (forehead flap) method involve reducing its thickness between the eyes, and creating the natural depression just above each ala. Such effects may be produced by excising pieces of skin in a wedge shape (Major Valadier), so that on suturing with horsehair (a mattress-suture is useful) the area is inverted. The superficial aspect of the excised piece is elliptical, and the depression produced is most marked at the widest part of the ellipse, gradually fading away towards its ends. By varying the relative length and width of the ellipse, and the slope of its edges, any sort of dimple, valley, or crease may be created.

After a wound in the region of the mandible, or at any stage of its surgical correction, an elevation or depression of one angle of the mouth is a frequent occurrence. When this is due to cicatricial contraction, there is no special point to emphasize here. But there are two other causes for such asymmetry which call for remark :—

1. Sometimes, after an extensive comminuted fracture of the lower jaw, with more or less loss of bone, it is impossible to maintain accurate apposition of the fragments by any form of splint; and these fragments, as Major Valadier first demonstrated to me, are often sufficiently viable to form callus, but will not tolerate wiring. There will be a dip in the level of the jaw on one side, dragging the angle of the mouth down with it. In such cases he devises, and his mechanicians make with a high degree

of finish, some form of bridge to raise the level of the depressed part, and on this bridge a denture is constructed. The angle of the mouth is now brought up by operation (see *Fig.* 118 C and E). It will be noticed that the mouth has eventually a false relation to the jaw on that side; but the dental occlusion is perfect, and the mouth straight. This is a better plan than to try to raise jaw and mouth together.

2. Destruction by an extensive wound of the facial nerve in the parotid region. Those who, like myself, have anastomosed the nerve with one of its neighbours, will agree that a completely successful result of this operation is rare. Here, again, it is better to lift the mouth angle by a plastic operation. The mouth in repose is then absolutely straight, and the patient's only obvious disability is a whimsically crooked smile.

SHORT NOTES OF RARE OR OBSCURE CASES.

A NOTE ON A CASE OF MYELOMA OF THE TENDON SHEATH.

BY FREDERICK C. PYBUS, NEWCASTLE-ON-TYNE.

IN view of the interest of these tumours, and the paper by Stewart and Flint in the BRITISH JOURNAL OF SURGERY in July, 1915, I publish this case, which I saw in consultation in July, 1912.

History.—The patient, Mrs. R., age 32, was the wife of a butcher. For the previous six years she had noticed a small tumour on the little finger of the right hand. During the last year it had grown considerably larger. It was occasionally painful, and prevented her from grasping anything or putting on a glove.

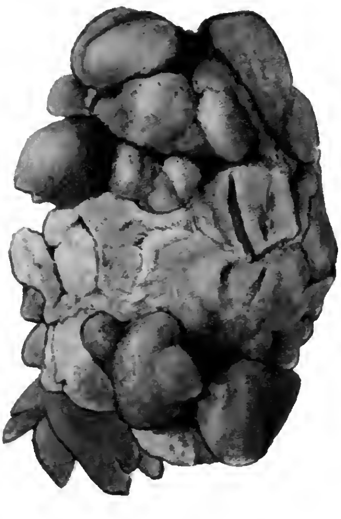


FIG. 127. -Showing the under surface of the tumour, with the tendon sheath at the centre. Yellow lobules on the left-hand side, and the band-like process at the lower and left-hand corner, are seen. (Twice natural size.)

Physical Signs.—The patient appeared generally healthy. There was present on the palmar aspect of the little finger, near its centre, an oval tumour about the size of a walnut. The skin moved over the tumour, which was lobulated and felt hard in some parts and elastic in others. The phalanges could be slightly flexed, demonstrating the freedom of the tendons. The tumour appeared to be attached to the tendon sheath.

Diagnosis.—The condition was new to me, and I could not give a definite opinion between (1) some form of ganglion, (2) neoplasm, (3) hyperplastic tubercle.

Operation.—A median incision was made over the tumour, which was found to be encapsulated and readily shelled from the surrounding tissue. It was attached by a broad base to the tendon sheath, a portion of which was removed. The sheath was closed over the tendon with catgut, and the skin edges were brought together. After removal I was still doubtful about the tumour. Drawings were made of it (*Fig.* 127), and a portion was submitted to microscopical examination.

Description of Tumour.—In size and shape it resembles a walnut.

The surface is deeply lobulated, one process resembling the fore paw of a mole. The general colour is reddish brown, while in some parts the lobules are greyish and appear translucent; in other parts they are of a yellow colour and look like wash-leather. A portion of the sheath is seen attached to the under surface of the tumour.

The late Dr. Sewell reported the specimen to be a myeloid sarcoma. The section has since been re-examined by Professor Stuart McDonald, who reports: "This appears to be a true myeloid sarcoma. The predominant cell is small and spindle-shaped, but there are numerous typical giant cells—in some fields, under the high power, from six to twelve of these are present. It is fairly vascular, and the vessels are of the usual sarcomatous type. In almost every part of the tumour there are extensive deposits of blood pigment, the result of hæmorrhage. The tumour is indistinguishable from the myeloid sarcoma arising in connection with bone."

The patient has remained quite well and free from recurrence or dissemination.

A CASE OF THROMBOSIS OF A CONSIDERABLE PORTION OF THE SUPERIOR MESENTERIC VESSELS WITHOUT ANY DISCOVERABLE CAUSE.

By OSWALD LACY ADDISON, London.

The following case seems worthy of record:—

Mrs. S., age 42, was waked up by a sudden severe pain in the abdomen at 3 a.m. on May 2, 1916. The pain continued without intermission during the day, and the abdomen became swollen. She vomited once, soon after the onset of the pain.

Patient had had no previous illness, and had gone to bed feeling perfectly well. The only possible exciting cause she could think of was that three or four days previously she had made herself very stiff and had felt 'seedy' after carrying some heavy flower-pots.

Patient, a slim, well-made woman, was admitted to the West London Hospital at 5.30 p.m. on the same day. She was pale and collapsed, with a very weak pulse of 100. The lower half of the abdomen was made prominent by a rounded, tender, elastic swelling looking like a five or six months pregnancy. The remainder of the abdomen was somewhat retracted. There was no visible peristalsis. Some dullness was present in both flanks. Examination of the pelvis was negative.

Operation at 6.30 p.m.—Condition at commencement very poor. On opening the abdomen a large quantity of blood-stained fluid escaped, and the swelling was seen to be formed by distended coils of small intestine lying transversely. The intestine was a dark plum colour, and about one and a half inches in diameter. On lifting the mass of intestines out of the abdomen there was no evidence of any kind of constriction of the mesentery, but all the vessels in the mesentery were thrombosed. The line of demarcation of the affected gut was absolutely abrupt, and ended below about three inches from

the ileocæcal valve. The gut immediately above the thrombosed part was empty and somewhat contracted. Clamps were applied, and after the removal of the affected gut with its mesentery, a lateral anastomosis was made to the colon just above the ileocæcal valve by simple suture. Owing to the collapsed condition of the patient a thorough examination of the upper half of the abdomen was not made, but the appendix and pelvic organs were seen, and appeared to be healthy. On account of the large amount of free fluid and the damaged intestine a small tube was left in for a few days, and the wound healed without infection.

Intravenous and subcutaneous saline were given during the operation, and rectal saline for two or three days after. The patient rapidly recovered from the operation, and next morning appeared to be, and said she felt, 'perfectly well.'

The temperature for the first four days did not rise above 99°, and the pulse remained 84–100. On the fifth and two subsequent nights the temperature rose to 100°, but afterwards remained subnormal. The bowels acted on the second day, and afterwards there were two or three loose motions daily.

No cause for the thrombosis was found. The patient was examined several times by Dr. Sidney Owen, but beyond a few carious teeth with no obvious pyorrhœa, a weak first sound and short apical systolic murmur, slight cardiac dilatation and weak myocardium, nothing was found. Dr. Owen did not consider that the cardiac condition was primary. The Wassermann reaction was negative. Patient left the hospital in three weeks, still rather pale, but feeling well.

Unfortunately, the piece of bowel removed was not measured at the time, and was by accident put into a strong solution of formalin. When measured four or five days later it was found to be nine feet in length. Seeing how much a piece of intestine contracts after removal, apart from the effects of immersion in strong formalin for four or five days, I think the original length cannot have been less than twelve feet, and was probably more. All the vessels of the corresponding mesentery were thrombosed, but it was not determined whether the condition was primary, or secondary to an embolism.

The most striking feature about the case was the rapidity with which the patient recovered from an apparently moribund condition—due chiefly, I think, to the fact that there was no distention of the bowel above the affected part with consequent absorption of toxins, and also to the use of spinal anæsthesia, which acted perfectly until near the end of the operation, when a very small amount of ether was given by the open method. The day after the operation the patient certainly appeared to be better than the majority of patients after a radical cure of hernia or an interval appendix operation.

The patient was seen ten months later, and seemed well, though rather pale. The weight had remained normal, and the bowels were still loose, acting as a rule twice a day. At intervals of three weeks there were attacks of griping abdominal pain followed by six or seven loose motions. She had not been able to influence the looseness of the bowels by diet. Recently she has had palpitation and some attacks of asthma, and menstruation has been irregular.

LOCALIZED TRAUMATIC OR DIRECT GANGRENE.

By Captain A. W. NUTHALL, R.A.M.C.(T.)

Private T., A.S.C., a despatch rider, fell off his motor bicycle on the stone setts of a French road. As he lay prone with his arms extended above his head, one rubber-shod wheel of a 3-ton motor lorry passed over both arms. Probably the lorry was bumping, or at least that particular wheel was not taking much weight at the moment of impact, for while the left arm sustained a severe crushing injury, the right arm escaped with mere abrasions (the man is positive that the wheel ran over both arms).

Fig. 128.

When seen on the fourth day, the left forearm presented the signs of a severe localized gangrene. There was no fracture apparent, the radial pulse was unaffected, and the condition of the forearm and hand distal to the injury quite natural. Two coloured photographs were taken which illustrate the lesion beautifully. For these I am indebted to Major A. C. Valadier. The man was in our hospital for thirty-six hours only, being transferred to England quickly in a period of great pressure. I cannot record his subsequent progress. He was seen by Colonel Burghard, at whose wish, and with the kind permission of Lieutenant-Colonel H. E. Sidgwick, the case is recorded.

A CASE OF FIBROID TUMOUR OF THE STOMACH.

By ERNEST W. HEY GROVES, Bristol.

T. C. M., age 50, a medical practitioner. There had been no previous illness until December, 1915, when, without any special warning, he had a fainting fit and passed a large quantity of blood by the rectum. In the following month he had an ordinary attack of acute pneumonia which ran

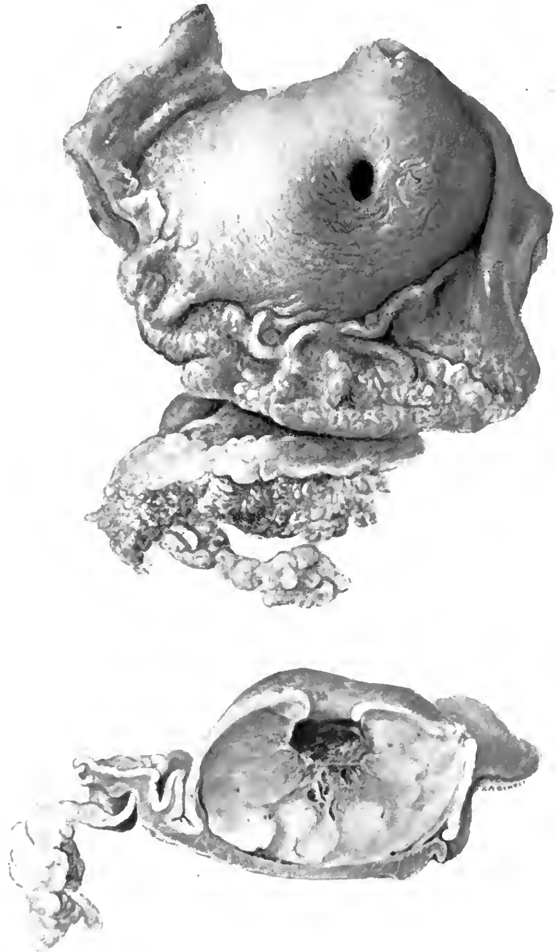


Fig. 129.—Fibroid tumour of the stomach. In the upper figure the tumour is viewed from the interior of the stomach; in the lower figure the tumour is seen in section.

a normal course. Between June and September, 1916, he had repeated attacks of melæna, but this was unassociated with dyspepsia, vomiting, or constipation. He became decidedly anæmic, and suffered from some palpitation.

Sept. 22, 1916.—Patient was well nourished and had a movable tumour in the right of the epigastrium.

Operation.—The stomach was exposed through a right pararectal incision; there were no adhesions. The organ presented a smooth soft tumour in the substance of the anterior wall. The middle third of the stomach was resected and an end-to-end anastomosis carried out without difficulty. The patient made a smooth recovery, and was able to return to his work at the end of the year. He is now in his normal health.

Description of Specimen.—The nature of the growth and its relation to the stomach are well indicated by the accompanying figures. The tumour, which was oval in shape, measured two and a half inches by one and three-quarter inches; it consisted of a soft vascular fibroid growth, exactly similar in every respect to a soft fibromyoma of the uterus. It lay in a loose connective-tissue capsule which separated it from the thickened muscular wall of the stomach on one side and from the mucous membrane on the other. The mucous membrane covering it presented two apertures, through which, no doubt, the hæmorrhage had occurred. One of these apertures was stellate and almost closed; this was probably the source of the hæmorrhage in December, 1915. The other opening was filled with recent blood-clot at the time of the operation, and it was clearly the seat of recent hæmorrhage.

At the time of the operation the tumour was regarded as probably sarcomatous, and therefore was removed with a wide margin of healthy tissue.

The occurrence of this type of fibroid tumour of the stomach is sufficiently rare to justify publication.

A CASE OF INTRAPERITONEAL PERFORATION OF AN ULCER OF THE URINARY BLADDER.

By Lieutenant-Colonel H. SIMPSON NEWLAND, A.A.M.C.,
and Captain H. RAYSON, A.A.M.C.

The interesting particulars of "A Case of Spontaneous Rupture of the Urinary Bladder," published in the October, 1916, number of The British Journal of Surgery, have led us to publish the following notes of a similar case.

Gunner H. F. J., after partaking freely of drink on the evening of Sept. 17, 1916, was knocked down by a motor car. He immediately felt severe pain in the lower part of the abdomen. At No. 3 London General Hospital a catheter was passed, and bloody urine withdrawn. On Sept. 20, four incisions were made into the anterior abdominal wall to allow the escape of extravasated urine. On Sept. 24, a suprapubic incision was made under an anæsthetic, and a rent $1\frac{1}{2}$ inches long was discovered in the anterior wall of the bladder. A large rubber drainage tube was introduced into the bladder through the tear. It was removed in the course of a few days. Six weeks later all the incisions had soundly healed.

On Feb. 2, 1917, the morning after admission to No. 1 Australian Auxiliary Hospital, he was suddenly seized with acute pain in the lower part

of the abdomen, whilst in the act of urinating. He completed the evacuation of his bladder, and with difficulty returned to the ward. On examination, he was in a state of collapse, the lips were pallid, the pulse was 130 and thready, and the temperature subnormal. The abdomen was tender all over, and did not move freely. He vomited once shortly after the onset of the pain. A slight result followed an enema, but no flatus was passed. At 2 p.m. a catheter was passed. The specimen of urine was cloudy, alkaline, and contained pus, triple phosphates, and numerous bacteria. The collapse passed off during the afternoon, the temperature rising to 100°. The pulse, however, became weaker and more rapid. The pain and tenderness tended to become localized in the left lower quadrant of the abdomen.

Operation was performed thirteen hours after the onset of the symptoms. A vertical incision was made through the left rectus, below the level of the umbilicus, and prolonged upwards later on. The omentum extended into the pelvis, and its extremity was inflamed. The pelvic coils of the small intestine were in a similar condition. The appendix being suspected, a search was made for it. The cæcum was thoroughly exposed, but no intraperitoneal appendix could be found. The cæcum was not inflamed. After a thorough search, and only after the pelvis was emptied, a tiny perforation was found low down on the peritoneal surface of the bladder. It was surrounded by pale yellow lymph. The opening was closed with catgut sutures, and a large rubber drainage tube was placed in the rectovesical fossa. The rest of the incision was closed. The patient was unable, after the operation, to retain a rubber catheter, so it was passed every six hours.

The subsequent course, except for free suppuration in the abdominal wound, has been uneventful.

This short record is entitled "A Case of Intraperitoneal Perforation of an Ulcer of the Urinary Bladder." The case recorded by Lieutenant-Colonel Sinclair White and Captain Wigram is an example of *extra*-peritoneal perforation. As these writers remark, perforation of a non-specific ulcer is a rare condition. It is interesting to remember that such a perforation may be either intra- or extraperitoneal.

REVIEWS AND NOTICES OF BOOKS.

Collected Papers of the Mayo Clinic. Edited by Mrs. M. H. Mellish. Vol. VII, 1915. Pp. 983 + xii, with 283 illustrations. London and Philadelphia: W. B. Saunders Co.

This volume, comprising the papers issuing from the Clinic in 1915, follows the lines of previous publications. Many of the articles deal with questions which were well worn in earlier volumes, such as goitre and ulcers of the stomach and duodenum; beyond elaboration of operative detail in connection with ulcers of the stomach there is nothing worthy of note in the latter papers: amongst those on diseases of the thyroid, there are several interesting speculative papers on the iodine content in goitre and on blood-pressure in thyrotoxicosis.

Dr. Robinson's paper on chronic empyema reviews most of the methods adopted by others for the treatment of these very troublesome cases, and will well repay perusal by those now dealing with such conditions resulting from gunshot wounds.

Two very interesting papers on plastic surgery are those by Dr. W. Mayo on wounds of the common bile-duct, and by Dr. Charles Mayo on a most ingenious method of closing a vesico-vaginal fistula. We are pleased to see the last-named turning his master hand to the technique of operations for spina bifida, though the paper contains only brief reference to what has been the most common type in the writer's experience at a children's hospital, viz., meningo-myelocele, and there is no suggestion as to the best method of dealing with the posterior nerve-roots in these very difficult cases.

Dr. Louis Wilson contributes a practical paper on the staining of sections of living tissues, which shows that the author has personally worked at, and exercised some original thought on, this subject. Sound experimental argument is the feature of Dr. F. C. Mann's study of shock, which he endeavours to prove is coincident with and dependent upon hæmorrhage; this section of the volume alone would save it from mediocrity, and we are inclined to think that on the institution of their Department of Experimental Surgery the Mayo Clinic may chiefly base a claim for gratitude from the surgery of the future.

The wider aspects of medicine, and its value and responsibilities for the national welfare, are touched on by Dr. Wilson in the final paper, which deals with necropsies as a Public Service; we welcome such a departure from stereotyped subjects as an intimation that the best minds of Rochester have thoughts outside publications of less permanent worth if of more immediate commercial value. The illustrations, particularly that by Miss Fry in Dr. William Mayo's kidney paper, are in every way admirable, and reflect credit no less upon the surgeon who chose their subject than upon the artist who gave his thoughts expression.

Le Traitement des Plaies Infectées. Par A. Carrel et G. Dehelly. Collection Horizon. Pp. 177, illustrated. 1917. Paris: Masson et Cie.

The Treatment of Infected Wounds. By A. Carrel and G. Dehelly. Translation by Captain Herbert Child, R.A.M.C. (temp.), with Introduction by Sir Anthony A. Bowlby, K.C.M.G., K.C.V.O., F.R.C.S., Surgeon-General A.M.S. Pp. 238. 1917. London: Ballière, Tindall & Cox. 5s. net.

This is an excellent book, and its appearance, both in its original French and its subsequent English form, is most opportune. All the military medical world is talking of the Carrel treatment, and no inconsiderable part of it is putting it into practice—not always, it is to be feared, exactly in the form of which its illustrious author would approve. This small volume gives the most exact details of the

method, and points out all the pitfalls and how they are to be avoided, and hence it should be in the hands of every one who is called upon to treat war wounds. It forms indeed the gospel according to Carrel, and no other instructions for the treatment that we have seen can be compared to it for wealth of detail, lucidity, or, of course, accuracy. Indeed, judging by some of the instructions for carrying out the method that we have seen issued elsewhere, this book will make clear to many for the first time what Carrel's treatment really is. It is quite possible that the "tendency to modify details" to which Sir Anthony Bowlby refers in his preface to the English translation, and which he rightly deprecates, is due rather to ignorance of what Carrel regards as the essential points in the method than to any desire to 'improve' upon the work of its distinguished author. At any rate there will be no excuse for blundering in future, for the book leaves no loophole for ignorance.

The 'Carrel treatment' is perhaps the most outstanding example of what can be done to solve a clinical problem when the research is carried out in the right manner. It is a triumphant combination of bacteriological, chemical, and clinical observation and experiment, and should bring about a closer working association between the laboratory and the clinical sides of research, which have unfortunately been too much separated in the past. Many an investigator in this war has found to his chagrin that methods which appeared to work admirably in the laboratory, and which were therefore somewhat rashly recommended, broke down hopelessly when the clinical test was applied.

It is to be hoped that the success achieved in the 'Hôpital Temporaire No. 21,' which may not unjustly be regarded as an experimental hospital set aside for the purpose of investigating the treatment of wounds, will render the Army Medical Departments of the whole civilized world thoroughly alive to the importance of purely experimental research work in the field, and that a sufficient number of hospitals of this kind will be provided in future, where the stay of the patient is not subject to military exigencies, and where, therefore, important medical problems will have a better chance of being solved than is possible under the conditions of rapid and repeated evacuation to which patients are still exposed in the present war, even at the base hospitals in France.

Concerning the method itself, this is hardly the time to speak at all unreservedly. That, under favourable circumstances, it will do what is claimed for it by its author, no one who has followed the practice at Compiègne or certain other places can doubt. But whether it is going to do this in the hands of all and sundry, time alone will show. The method has encountered the usual fate of these things. First, it was ignored; then it was said to be a good thing in skilled hands, but no use for the general; now it is entering the penultimate stage—the stage, that is, in which everyone is doing it. And so we shall work on to the final stage, when it will be possible to get a true perspective and to estimate its real value. In the meanwhile this volume will lead many into the straight path, and prevent their footsteps from straying.

The book is admirably written, and has been excellently translated by Dr. Herbert Child. It is delightfully clear and easy to read in either language. Sir Anthony Bowlby furnishes the English translation with an Introduction on the value of the method, and he sounds a rather more optimistic note than a good many critics would venture upon, especially since his remarks apply only to cases at the front, and deal only with the comparatively short time during which the method has been actively employed in the British Army, i.e., since the late autumn of 1916. The real value of Carrel's method as a war treatment must stand or fall according to the results secured by military surgeons in general, and not by what it can achieve in the hands of skilled individuals. Nothing in this war has been more striking to an onlooker who has had the opportunity of seeing the practice of many men than the importance of the personal factor in the success or failure of various lines of treatment. The only unsatisfying point about the book before us is that it does not contain statistics of a large number of cases treated by the rank and file of the profession. From the nature of things this could not be expected; but the book will certainly be the means of rendering such statistics available before very long.

JOHN HALLE.

1529–1568.

John Halle belongs to that band of educated surgeons who endeavoured during the reign of Elizabeth to raise the status of surgery in England and to restrain quacks. Vicary, Gale, Clowes, Banister, and Read were the leading spirits in the crusade—all men worthy of the utmost reverence from us, their successors; for when the lamp of surgery was burning very dimly in England, they replenished it and handed it on newly trimmed. Vicary, Gale, and Clowes were London surgeons; Halle, Banister, and Read practised in the provinces, yet were in close touch with their colleagues and friends. They formed a little band, working to a common end and introducing each others books with eulogies in very bad verse. All were members of the United Company of Barbers and Surgeons created in 1545; indeed it is possible that the union of the Guild of Surgeons and the Company of Barbers was in part due to the direct efforts of the older members.

Halle and Read have proved themselves the most elusive of the band: of Vicary, Gale, and Clowes some memorials still exist. The utmost diligence of Mr. J. H. Allchin, the Chief Curator and Librarian of the Museum and Public Library at Maidstone, only shows that Halle was implicated in Wyatt's Rebellion in 1554, for which he was imprisoned but subsequently pardoned and released; that he died in October, 1568, at the age of 39; and that he was buried in All Saints' Church in his native town. From his own writings, we know that he practised in Maidstone, where he was held in respect by his fellow-townsmen; that he was a stout Protestant, as might have been expected from his implication in Wyatt's rebellion; that he was married, his wife dying on June 16 (? 1561); that he was gifted with a keen sardonic humour; that his beard was black and he was of a choleric temperament.

The work done by Halle in his short life was considerable, and he must have begun it early, for in 1550 he complains that "certayne chapters taken out of the Proverbes of Solomon with other chapters of Holy Scripture and certayne Psalmes of David translated (by him) into English metre" had been unfairly attributed to Thomas Sternhold, and at this time he was not more than twenty years old. His extant works are:—

1. A small quarto volume, "imprinted at London in Flete Streate nyghe unto Saint Dunstanes church by Thomas Marshe An. 1565," containing: (*a*) A translation of Lanfrank's smaller surgery; (*b*) An expositive table of the strange words used by Lanfrank, amongst which is 'algebra': "This Arabye worde Algebra sygnifieth fractures (as of bones &c.)"; (*c*) A treatise of anatomy, in three parts; (*d*) *An Historiall Expostulation against the Beastly Abusers bothe of Chyrurgerie and Physyke in oure time.* The last tract is priceless as a picture of the times, and of Halle's method of treating quacks. It was republished by the Percy Society in 1844, when it was edited

by T. J. Pettigrew. Prefixed to this volume is a portrait of John Halle, with the date 1564 and the inscription "J. H. anno ætatis suæ 35." It represents him with a jewelled ring on the right index finger, wearing the cap of a Master of Surgery, and in his hand a sprig of vetch.

2. In the same year he issued *The Courte of Vertue containing many Holy or spiritual songs, sonnettes, psalmes, Ballets and short sentences as well as of Holy Scriptures as others with Music notes*, 16mo. The *Courte of Virtue* is nearly as good as the *Historiall Expostulation*, and it is one of the class of books which made the early puritans acceptable to the people, for it set the scriptures to tunes which could readily be sung, whilst it satirized with no sparing hand the foibles of the time.

3. A volume of manuscripts which once belonged to John Halle still remains unpublished at the Bodleian Library. It contains amongst other things a translation of Benedictus Victorius on Syphilis, conceived on the same lines as the translation of Lanfranc.

Halle says of the Lanfranc, that "it was translated oute of French into the olde Saxony English about two hundred years past, which I haue nowe not only reduced to our usuall speache by changying or newe translating suche words as nowe be inveterate and growne oute of knowledge by process of tyme, but also conferred my labours in this behalf with other copies both in French and Latine; namely with Maister Bacter for his latine copy and Symon Hudie for his french copie and other English copies of the which I had one of John Chamber and another of John Yates both very ancient." A comparison of Halle's translation with the editions of Lanfrank published in 1380 and 1420 shows that it does not correspond with either, even if allowance be made for a process of severe editing at Halle's hands. The statement is valuable, because it gives a possible clue to the mystery surrounding the origin of *The Englishman's Treasure* published by Vicary a few years earlier.

The *Anatomy* is a mere compilation of mediæval knowledge, without reference to the newer teaching of Vesalius which had already been accessible for nearly a quarter of a century. Halle says that he was encouraged to publish it "by the example of good Maister Vicarie, late sargeaunte chirurgian to the Queen's highness who was the first that ever wrote a treatyse of Anatomye in English (to the profite of his brethren chirurgians and the helpe of younge studentes) as farre as I can learne."

The real value of Halle's work lies in his determined attempt to advance the social position of the surgeon, by insisting upon a higher standard of education for the apprentice, a knowledge of medicine as well as surgery by the practitioner, and a rigid suppression of quackery by the United Company. The union of Barbers and Surgeons was still so recent that the commercial spirit of the Barbers remained in the ascendant, and the United Company was rather too ready to increase its numbers without regard to the education or even to the character of the candidates for admission. Medicine had become entirely divorced from surgery, and in the absence of scientific knowledge quackery was rampant. Each of these conditions is amusingly exposed in Halle's writings. He says, in reference to the apprenticeship system: "For truly there are many that take servauntes and apprentices not for to teach them science but only to be their drudge and to doe their toyle and labore,

JOHN HALLE.

Reproduced from the frontispiece of Halle's translation of Lanfrank's smaller surgery.

which is the cause that so many come oute of their yeares so ignoraunt. For their interest is to have servauntes to dooe their toyle in their house and not to make them cunnyng men ; yea, and some will refuse a young man that is learned and apt to understande to have an ignoraunte slave to beare the water tankard and scoure pannes ; such an one (as the common proverb is) that will never doe a man of science harme unles he steale away his dynner."

The antagonism of medicine to surgery is referred to in the following manner : " For as physicians thynke their learning sufficient without practice or experience so the chirurgien for the moste parte, having experience and practice, thinketh it unnedeful to have any learning at all which also hath boldened every ignoraunt, rusticall, yea, and foolish woman to think themselves sufficient to professe and worke in so noble and worthy an arte."

The attempt to consolidate medicine and surgery failed, as it had already failed in 1421, and only became an accomplished fact in England in 1886, when the Royal College of Physicians agreed with the Royal College of Surgeons to establish a conjoint examination. The efforts of Halle and his friends bore some fruit, however, for in 1566, the year after the *Historiall Expostulation* was published, Thomas Hall—his younger brother—was given an Exhibition by the Barber Surgeons of 40s. " towards hys studie in the Unyversitie for surgery annexynge physicke thereunto and thereby to profit his other brethren by readynge lectures unto them in the Comon Hall." Thomas Hall made good use of the start thus given to him. He was of Broadgates Hall, Oxford ; obtained a licence in medicine March 17, 1571–2 ; was appointed Dissector of Anatomy at the Barber Surgeons' Hall in 1577 ; graduated M.D. at Oxford in 1581 ; and was chosen a Fellow of the College of Physicians in 1585.

Writing of quacks, John Halle says : " Ther came into the towne of Maydstone in the yere of our Lorde, 1555, a woman whiche named hir selfe Jone, havyng with hyr a walkyng mate whom she called her husbande. This wicked beaste toke hir inne at the sygne of the Bell where she caused to be published that she coulde heale all manner both inward and outward diseases. This beastlie deceaver amonge manie others, tooke in hand an honest mans child who had a suppurat tumour in his navell, pereynge dangerously the panicles of the belye, to whom she administered a powder [made of the herbe daphnoydes and anise seed together] in great quantite in so much that the childe dyd vomite continualle for the space of halfe a daye and more withute ceassynge whereby the said aposteme brake. The childis parentes did send for me to know therein myne opinion and counsell : unto whom I prognosticated (as I sawe good cause) that the matter was very dangerous and not lyke to be cured. But this beastly forme of a woman hearyng me so saye answered that she douted therein no daunger and farthermore offered hirselfe to be locked up in a chamber with the chylde and that yf shee healed him not shee myghte be punished ; with a great deal more circumstance of prating and dyceytfull braggynge wordes. Unto whose moste wicked and divlishe boldness I thus answered. Wher as you saye that ye doubte not any daunger in this childe I verye well beleve you, for ignorante fooles can doubte no perils, and who is bolder than blynde bayerd ? how shoulde they doubte that knowe not what a doubt meaneth ? Nothwithstandynge,

this preheminence you deceavynge rennegates have, ye maye bragge, lye and face tyll ye have murdered or destroyed suche as credyte you and then are ye gone, ye shewe your heles and that is onelye your defence. But honest menne of arte muste have truthe for theyr defence and maye promyse no more than they may performe.

"What should I make manye wordes, the parentes of the childe all to late discharged this deceaver and the child, notwithstandyng the counsell had of dyvers learned men, dyed afterwards of the sayde grefe. But the sayde deceaver accordyng to my prophesie, after iij. dayes ran away, she and her walkyng mate robbynge their hoste where they lay of the shetes, pillow-beres and blankets that they laye in and they hadde muscadell served them instede of bere whyle they laye there for the moste parte.

"Secondly in the yere of our Lord 1556 there resorted unto Maydstone one Robert Harris who could tel by only lokyng in ones face all secrete markes and scarres of the bodye and what they had done and what hadde chaunced unto them all theyr lyfe tyme before. . . . . Well for jestyng a lyttell agaynste the madnes of thys deceaver, I hadde a dagger drawn at me not longe after." Halle's jesting on quacks was mordant, so the attempt on his life was well justified in the eyes of his victim.

"Thyrdlie in the year of our Lord a thousand fyve hundred and fyftie and eight there came to Maydstone one Thomas Lufkyn the beastliest beguiler by his sorcerys that ever I herd of, making physike the onely colour to cover all his crafty thefte and mischieves. This vileyne coulde wyth a wodden face bragge, face and schoute his maters wyth bould talke that the symple people wer by him marvelously seduced to beleve his lies and boastinge tales.

"Fourthlye in the yeare of our Lorde a thousand fyve hundred and three score, one Valentyne came into a parish in the wolde of kente called Staplehurst callynge hymself Master Wynkfylde affirmynge hymselfe to be the sonne of a worshipful knight of that name. But as tyme revealeth all thynges so this devylyshe beaste in shorte tyme was knowne in his righte kynde and name: and that he had iij wyves lyving at that present, of which the first lyved very poorelye and myserably in Canterbury: the second after she knewe his wickednes, departed from him and maried after with a preste: the third which he at that present had, he maried at Westmynster, being there a riche widowe."

So there are many other entertaining accounts, full of detail, about quacks and their ways; but in the end Halle returns to his original theme, and declares his faith in these words: "As I would therefore that all chirurgians shoulde be learned, so woulde I have no man thinke him selfe lerned otherwise than chiefly by experience; for learning in chirurgery consisteth not in speculation only, nor in practice only, but in speculation well practised by experience. Therefore when we saye that a chirurgian muste firste be lerned and then worke, it is not ment that any man by the reading of a booke or bokes onlye, may lerne how to worke for trulye that hath caused so many deceivinge abusers, as there are at this daye."

METHODS AND RESULTS OF TRANSPLANTATION OF BONE IN THE REPAIR OF DEFECTS CAUSED BY INJURY OR DISEASE.

By ERNEST W. HEY GROVES.

I.—HISTORY AND LITERATURE.

The transplantation of bone, depending as it does upon the fundamental facts of bone structure and growth, has been the subject of much experimental and clinical work, which during recent years has received a great impetus by reason of the improvements of surgical technique and the possibilities of excluding septic infection. But although many painstaking observations have been made, the theoretical aspect of the question is still a matter of strongly divided opinion. So divergent indeed are the views held by leading workers, that a feeling something akin to despair is aroused in the mind of the seeker after truth—not so much by mere differences of opinion amongst the observers, but by the apparent contradiction of the facts observed. Yet in sharp contrast to the antagonistic state of opinion about the theory of bone growth, there has slowly emerged a most healthy and encouraging unanimity in regard to the practical aspect of the subject. This leads to the conclusion that, as the preliminary collection of experiences and observations has afforded foundation for a very solid superstructure of practical results, therefore the foundation must after all be both solid and lasting. And instead of giving up in despair all attempts to reconcile conflicting evidence, the student is encouraged to go back and examine piece by piece the work that has been done; and he will certainly be rewarded for this by finding that in reality truth itself has been immutable, and differences of opinion have arisen from the bias of preconceived views, and from a narrowness of outlook which can now be corrected.

Havers,[1] whose name has ever since been identified with the vascular canals in bone, in 1692 gave the first accurate account of osseous structure, and he described the periosteum as simply a connective-tissue, limiting, and vascularizing membrane. Antoine de Heyde[1] in 1684 published the first experimental observations, made on frogs, and came to the conclusion that callus was formed by calcification of blood-clot extravasated round the broken bone ends.

It was, however, in the middle of the eighteenth century (1739–1743) that the first systematic work on this subject was carried out by Duhamel,[1] who was the originator of the modern, generally accepted theory of the function of the periosteum. In his view the periosteum became thickened and succulent round a fracture, and by pushing the new tissue in amongst the fragments it formed the callus. He it was who founded the term 'cambium

layer' of the periosteum which is now in every-day use, especially in German literature. Eighteen years later, Troja[1] produced experimental necrosis of the long bones by introducing foreign bodies into the medullary cavity, and described the formation of new bone between the periosteum and the dead shaft.

A century after Duhamel, after many less remembered works and discussions on the subject had appeared, came the great work of Ollier[2] (1867), which remains to-day a classic of surgical literature. Ollier's work was so thorough and so careful, that his conclusions have attained an almost unassailable position. Unfortunately, that part of his work which related to the apparent osteogenetic function of the periosteum has taken so firm a hold upon surgical teaching, that the remainder has been overlooked or forgotten.

During the last fifty years, as a part of the growth of modern surgery, many experimental and clinical observations have been made as to the behaviour of transplanted bone and the results obtained by its use. For the most part these have been isolated examples, often regarded as curiosities or rarities of surgical daring, not calculated to lead to any practical modification of routine surgical practice. But there have been three men since Ollier whose work has marked an epoch in our knowledge. These are Barth, Axhausen, and Macewen.

Barth[3] in 1893 showed that in spite of the smooth healing of bone-grafts, the greater part of the cellular contents of the transplanted bone underwent necrosis, and he went so far as to deny that there was any difference between the behaviour of a graft of living bone taken from the same animal, that from another animal, or boiled and devitalized bone. But as he has since abandoned this extreme view, we may ignore it, whilst still placing to his credit the observation of the fact, now generally admitted, that the greater number of the cells of the compact tissue of a bone-graft actually die.

Axhausen[4] in 1898, dominated by the idea—then universally held—that the periosteum was the principal agent in osteogenesis, collected a number of clinical and experimental facts which he took to prove that both the periosteum and the endosteum in grafts survive transplantation, though the cells of the compact bone die. His evidence was so convincing that Barth abandoned his idea of a bone-graft being a dead scaffold, and admitted that a living, periosteum-covered graft took an active share in bone regeneration.

Then, in 1911, Macewen produced his work *The Growth of Bone*,[5] which with direct and almost staggering simplicity tended to overturn all our views of osteogenesis. He denied that the periosteum was anything but a limiting membrane, and he ascribed to the osteoblasts all the phenomena of bone growth and repair. Unfortunately Macewen was content to record his own observations, without attempting to explain their apparent discrepancies with those made elsewhere, and it has been left for others either to attempt this task, or to content themselves with tabulating lists of divergent views, and the apparently contradictory facts upon which these views are founded.

Since the appearance of Macewen's volume, many other papers have appeared, for the most part confirming what he demonstrated, but to some extent confuting it. It seems quite possible, however, at the present moment

to collect together the principal writings on this subject, and by a critical examination of the facts presented, to build up a perfectly consistent narrative of the sequence of events in bone growth in relation to grafting. Although at present the opinions of the various protagonists may appear to be widely divergent, yet all the facts upon which they base their conclusions are susceptible of a harmonious interpretation. In the attempt to make this critical examination, it will be convenient to summarize the work of Ollier, Barth, Axhausen, and Macewen, then to present a unified statement of the stages in the history of a bone-graft as deduced from these observations, and lastly to refer briefly to some of the other more recent literature in its bearing upon the points in question.

Ollier's Work.

Ollier has embodied his observations in two volumes, entitled *Traité Expérimental et Clinique de la Régénération des Os*, published in Paris, 1867.

It will only be necessary for the present purpose to summarize the contents of the first volume dealing with the experimental work. The clinical practice of those days, not being subject to confirmation either by the microscope or by the *x* rays, does not lend itself to critical examination. His experiments were performed mostly on quite young dogs and rabbits. His actual observations were as follows:—

1. A flap of periosteum lifted from the tibia, but left attached at its base to the bone, turned round a muscle, produced a ring of bone.
2. The same experiment was repeated, but the base of the flap was divided after four days: a bony ring was formed.
3. A flap of periosteum, taken from the tibia, and transplanted into the frontal region, within forty days formed a new bone with a distinct medullary cavity.
4. A dura-mater flap, transplanted into the groin, produced a scanty bone deposit.
5. A flap of periosteum, if scraped on its deep surface, does not produce bone.
6. An emulsion made from the scrapings from the deep surface of the periosteum, transplanted into the thigh, produces small bone nodules.
7. In the formation of new bone from periosteum, sometimes cartilage precedes bone formation and sometimes not.
8. A mild degree of suppuration does not prevent osteogenesis.
9. Free transplantation of marrow tissue does not produce new bone.
10. After amputation through the middle of a long bone, a thin metal cylinder was introduced into the marrow cavity, and this became filled with new bone.
11. If the periosteum is stripped from a bone, the latter regenerates a new periosteum.
12. If, after the removal of the periosteum, the bone is scraped, the formation of new periosteum is prevented or retarded.
13. New periosteum formed from old bone can also in its turn reproduce new bone, though not so freely as in the case of normal periosteum.

14. If bone is deprived of its periosteum, it continues to live, and increases not only in thickness but in length.

15. If bone is deprived both of its periosteum and its marrow, it continues to live, and its ends undergo hypertrophy.

16. If bone is deprived of its periosteum and is surrounded by metal foil, it still grows in thickness, by encroachment upon the marrow cavity.

17. Bone deprived of its periosteum and then fractured, unites by a process of normal callus-formation.

18. Section of the nerves produces no effect upon the healing of fractures.

19. When a whole bone is removed subperiosteally from a young animal, a new bone is reproduced, which is longer and thicker than that removed.

20. If a whole bone is removed with its periosteum, no new bone is reproduced.

21. If a joint is resected in a young animal, with preservation of the capsule, the joint is reproduced. This succeeded best in the elbow and the knee.

22. The above experiments with young bones succeeded equally well with long bones, flat bones (scapula), and short bones (os calcis).

23. In an adult dog, subperiosteal resection gave no new bone.

24. In an adult, if, prior to resection, the periosteum is stimulated (by cutting the periosteum and boring the medulla with a stylet), then a little ossification results after resection.

25. If after subperiosteal resection the resected part is replaced, a more massive bone than before is produced. He attributes this to irritation of the periosteum, and says that the same thing happens if a foreign body is made to replace the resected bone.

26. He confirmed the experiments of Hunter and Flourens proving that the growth in the length of bone is from the ends of the diaphysis, and showed that in all long bones the rate of growth is always much greater at one end than at the other.

27. The growth of cartilage is interstitial.

28. Destruction of the epiphyseal cartilage prevents the growth of a bone in length.

29. Bone formed from a free transplantation of periosteum is absorbed after a short time.

30. Periosteal new bone can be grafted from one animal to another of the same species.

31. Whole bones can be grafted from one animal to another of the same species. In such a case the graft grows in thickness, but not in length, and the graft remains vascular.

32. Fragments of bone, without periosteum, will live when grafted. Ollier thought that this only took place after vital connection had been established between the grafts and the periosteal or marrow tissue of the bed.

Ollier's investigations were thus much more extensive and his views much wider than they might be judged from quotations in recent literature. As far as they go, his experiments and figures are beyond criticism, but the histological aspect of the subject was not touched upon, neither of course was any radiographic evidence available. That he took an exaggerated view of

the rôle of the periosteum may be true, but nevertheless he quite clearly states that the periosteum in flaps or in transplants is only fully osteogenetic in young animals, and that it is not so in adults. He points out that the compact bone can live, grow, and undergo repair, quite independently of its covering membrane, and he shows that osteogenesis lost in the adult periosteum could be revived by stimulation of the compact bone beneath; he proved the viability of autogenous and homogenous grafts, and he recognized that separate living bone fragments without periosteum could live and grow in a suitable environment.

Barth's Work.

Barth's[3] researches have nothing like the same importance as those of the other three pioneers; but they have had a very wide influence, both in founding the idea that bone-grafts simply act as a passive scaffolding, and in stimulating further research such as that of Axhausen, which has given us a much fuller knowledge of the details of bone regeneration.

Barth's first papers (1893) are concerned with the microscopic appearance of pieces of bone placed in trephine openings in dogs' skulls. In most cases a trephine disc was immediately replaced, but in others a bit of sterilized macerated bone was used to fill the gap. His findings may be summarized as follows :—

1. To the naked eye there is no difference between the behaviour of dead and living bone-grafts when observed after comparatively short intervals (13–61 days).

2. The whole of the substance of the compact bone of a graft dies, judging from the empty cell spaces.

3. There is great proliferation of connective tissue (i.e., granulation tissue) from the outer surfaces of the dura mater. Between this and the graft there appear islands of new bone and areas of callus formation. (This is only shown in his figures in the case of living bone-grafts.)

4. There is absorption of the dead tissue of the bone-graft, and a formation of new bone, which grows into the graft from the surrounding living bone.

5. New bone is also deposited in marrow spaces of the graft where these lie open and exposed to living tissue.

6. New bone makes its appearance in and around the Haversian canals of the dead bone.

Upon the somewhat slender foundation of these observations, Barth proceeded to build the superstructure of his theory that, for grafting purposes, autogenous living bone, with or without periosteum, and homogenous, heterogenous, and macerated dead bone, all behave alike. The value of his observations in relation to the general subject of bone-grafting is vitiated by the following facts: (*a*) They are founded on the study of the skull; (*b*) They only cover very short periods; (*c*) He assumes, without sufficient evidence, that new bone formation in relation to a living graft all comes from the surrounding bone and not from the graft itself. He actually figures the following elements of new bone formation: callus between the dura and the graft; callus between the graft and the surrounding bone; new bone tissue in the enlarged Haversian canals and in the marrow tissue of the graft. Clearly any or all

of these elements of new bone may have been derived from the living graft, a suggestion which is supported by the fact that they are either absent or not apparent in his own figure of the transplantation of a dead bone.

But though Barth himself has abandoned the view that a dead and a living graft behave in the same way, yet his work has established the facts that a graft is slow and indolent in the matter of growth, that the greater part of the compact bone dies, and that final success in grafting depends very largely upon the intimate contact of the graft with the living vascular bone of its bed.

In 1908 Barth[6] admitted that living periosteum-covered bone was the best graft material for securing active new bone formation, but he maintained that, for the mere filling of holes in a skull or the long bones, dead bone chips or bone dust formed the best material. He relates a remarkable case of a girl of 17, who had had multiple spontaneous fractures. He treated these on different occasions by open osteotomy, filling the marrow cavity with dead bone dust (*knochen kohle*), with uniform success. This observation will be referred to later.

Axhausen's Work.

In 1908 Axhausen[4] published a most careful and exhaustive paper giving an account of 146 animal experiments in bone-grafting, together with a very detailed histological account of his findings. His experiments included transplantation of pieces of bone into the soft tissues, and into other bones; autoplastic, homoplastic, and heteroplastic grafting; grafting of bone with and without periosteum and marrow; and grafting of boiled bone. He carried out these experiments with rats, rabbits, and dogs. His work contains such a wealth of detail that it is difficult to do justice to it in a summary. The following are his chief points :—

1. A living periosteum-covered graft shows marked cellular proliferation under the periosteum.

2. A graft containing marrow shows new bone formation from the marrow tissue wherever this is in contact with living vascular tissue.

3. The compact bone of a graft, whatever be its source, always exhibits empty cell spaces in the greater part of its extent.

4. The disappearance of the cells from the compact tissue of a living graft proceeds from without inwards, and is preceded by a shrinking and deformity of the nuclei.

5. He admits, however (p. 120), and figures (*Fig.* 9, *Pl.* 2), that certain areas occur in the edge of the compact bone where the cells retain their staining properties. This was seen best in the pieces of bone close to areas of periosteum or marrow which had retained their vitality. He admits that it is uncertain whether such areas may represent foci of new bone production, though he assumes in his conclusions that they do not.

6. The dead compact bone is rebuilt by successive stages of absorption and apposition of new bone formed beneath the periosteum, from the marrow tissue, and in the channels made by new vessels which penetrate the old dead bone.

7. He figures (e.g., *Fig.* 17, *Pl.* 4) new bone laid down round vessels in the widened Haversian canals of the graft. It is not clear why he assumes

that these have all grown in from outside, instead of having arisen from survivals of the cells of the original compact bone.

8. The periosteum has a capacity for survival, proliferation, and production of new bone, but it does not survive in those parts where muscle tissue or blood effusion prevents its organic growth to surrounding tissues.

9. At the cut edge the periosteum shows a more marked tendency to proliferation than elsewhere. Longitudinal incisions of the periosteum increase subperiosteal new bone formation.

10. The marrow is also osteogenetic, but only where it is in immediate contact with living tissues, i.e., at the cut ends or along a split bone.

11. Bone taken from another individual of the same species shows exactly the same behaviour as one taken from the same individual, but the viability and osteogenesis are both of a lesser degree.

12. Bone grafts without periosteum are far inferior to those covered with periosteum, both in viability and osteogenesis.

13. He admits, however, the viability of pieces of nude bone, saying that survival depends upon retained marrow tissue and on the existence on the outer surface of irregular deposits of "osteogenetic layers of the periosteum," from both of which new bone is laid down.

In 1911, in a later paper,[7] Axhausen adds certain valuable observations of a clinical character, and he summarizes the differences between his views and those of Barth. In a patient, age 23, a graft of the periosteum-covered fibula was implanted in the shaft of the femur, the upper part of which had been resected for a fibroma. A marked increase occurred both in the thickness and density of the graft, but this only began after five months, and was rapid between the twelfth and eighteenth month. He holds that this delay was due to the time taken by the substitution of the dead compact bone by the periosteal new bone. In a second case, a man of 31 had a piece of tibia grafted in place of a metacarpal. After sixty days it became dislocated, and the end had to be removed. This specimen confirmed his experimental findings—i.e., there was marked proliferation of cells under the periosteum, and especially at its cut edge; the great mass of compact bone showed empty cell spaces; and at the cut edge of the bone there was marked lacunar absorption and substitution.

The great and lasting value of Axhausen's work is the wealth of detail which he gives of the microscopic processes in bone-grafting. His inferences from, and interpretations of, the structure he describes are often open to criticism. That the greater part of the compact tissue of the graft suffers the loss of its living cells is fully conceded now by all authorities, but as Frankenstein, Woolf, and David have all pointed out, a certain number of cells appear to survive, and these are actually shown in Axhausen's own figures. Then, again, the assumption that the new bone cells in the Haversian canals have all migrated into the bone from outside the graft is by no means proved. That Axhausen is so strongly biased by a preconceived idea of the osteogenetic function of the periosteum as to be incapable of taking a fair view of matters relating to it, is shown by the remark (*Archiv. f. klin. Chir.*, 1911, vol. xciv, p. 277) that no tissue could be regarded as periosteum unless its osteogenetic function could be demonstrated!

Macewen's Work.

Macewen's[5] conclusions were the result of a very long and wide experience of the clinical events in bone surgery, and of animal experiments, chiefly upon dogs. His principal observations are as follows :—

1. Young dog's radius : resection of part of the whole thickness of the bone, leaving the periosteum. No bone was formed by the periosteum in ten weeks, but the gap was nearly filled by epiphyseal growth pushing the two ends towards the gap, and by proliferation at the cut ends of the bones.

2. Young dog's radius : resection of the whole bone, including the epiphyseal cartilages, but preserving the periosteum No new bone formed in six weeks.

3, 4. Failure of periosteal flaps to produce new bone.

5. Free periosteal transplant produced only a small nodule of bone in five weeks.

6. Removal of the entire periosteum did not affect the life and growth of the bone.

7, 8, 9. Silver rings, placed round a bone bereft of its periosteum, became buried in new bone, which must have arisen from the compact bony tissue.

10, 11. Portions of the radius from two different dogs removed, broken into pieces, and replaced, exchanging the bone of the two dogs. This was done after removal of the periosteum. Yet a massive piece of new bone was formed in each case. (In both cases there is very marked hypertrophy of the bone into which the graft is made, and in one—*Fig.* 15 in Macewen's book—the massive bone is shorter than normal. These points will be discussed later.)

12, 13. Homoplastic grafts of the whole radius without its periosteum exchanged between one dog and another. Perfect union, accompanied by decided thickening of the bones, occurred after eleven weeks.

14, 15. Shavings of nude bone placed in a gap in the radius in two young dogs. In both cases a big mass of new bone was formed. (As in 10 and 11, the original bone fragments are much thickened, but the bone as a whole is shorter than normal—in one case by a quarter of an inch, and in the other by five-sixteenths of an 'nch, in a five-inch bone.)

16, 17. Nude bone shavings implanted into muscle and peritoneum survived, growing in one case but atrophying in the other.

18. Transplantation of bone dust showed no bone growth.

19. Bone tissue was demonstrated growing into a piece of decalcified sponge placed in a bone gap.

20, 21. A glass tube was placed over the cut end of a bone, and bone tissue demonstrated growing into the glass tube.

22, 23. Free bone growth apart from periosteum was demonstrated in two human cases. In one it formed inside an aneurysm, the parent vessel of which had been perforated by a bone spicule. In the other it was formed in muscle in relation to a fracture.

24. A piece of bone was removed with its periosteum from the radius of a young dog. The gap became filled up, and the new piece of bone proliferated among the muscles surrounding it.

25, 26. Firm bone growth following re-implantation of skull fragments in

human subjects ; in one case the piece was replaced as a mosaic, and in the other as a whole fragment.

27. Subperiosteal resection of the radius, leaving a quarter of an inch of diaphysis at each end. After six weeks the shaft was re-formed. In the operation the upper epiphysis had been damaged, and from this the growth was weak ; from the uninjured lower epiphysis it was vigorous.

28. Removal of the periosteum of the radius and resection of all the diaphysis except its two ends ; the ends of the bone were capped with metal caps. After seven weeks the bone was re-formed, and the metal caps had been pushed past one another.

29, 30. Growth in length of bones arrested by excision of epiphyseal cartilages.

31. In a boy, the humerus was lost by osteomyelitis. No new growth occurred. On three different occasions several bits of bone from other children's tibias were inserted, each graft being about 1½ in. long. Thirty years later the humerus was entire, 11 inches long ; the grafted portion could still be distinguished as a part 4½ in. long near the lower end of the new bone.

32. Girl's jaw replaced by naked rib fragment with successful result.

Macewen's work derives great force from its very terseness and simplicity, and also from the association of experimental with clinical teaching. Its great lack is the absence of microscopical detail.

At the risk of making the present paper a bald reiteration of the work of others, I have set out above the main facts observed by Ollier, Barth, Axhausen, and Macewen, instead of merely giving their opinions and deductions. In this way only is it possible to examine the question of the unity of their discoveries, or to attempt to reconcile the divergences of their deductions.

AN ATTEMPT TO RECONSTRUCT A NARRATIVE OF BONE GROWTH FROM THE WORK OF THE FOREGOING AUTHORS.

1. The Rôle of the Periosteum.—We are met at the outset with the difficulty of one series of subperiosteal resections producing new bone and another producing none. But this is really not difficult of explanation.

a. In the first place, Ollier himself observed (obs. 23, *supra*) that periosteum formed no new bone in an adult after resection.

b. Secondly, in the case of a young bone, when a portion of its whole thickness is removed, leaving the periosteum, after a short time the gap is filled with new bone. All agree about this ; but as Macewen has shown, the filling of the gap may come from two sources other than the periosteum, viz., from the epiphyseal cartilage pushing the cut fragment towards the gap, and from proliferation from the cut ends of the bone. Therefore all experiments of this nature have no bearing on the osteogenetic function of the periosteum, since a gap in a long bone can be equally well filled up after that membrane has been removed, provided the epiphyseal cartilages remain intact (Macewen, obs. 28).

c. The most difficult facts to reconcile are the subperiosteal resection of a whole bone being in one case followed by regeneration and in one not. (Compare Ollier, obs. 19–21, with Macewen, obs. 2.) However, both authors clearly indicate the explanation. Ollier showed that if the periosteum was used

without its deep layer, then no bone was produced even in young animals (obs. 2); again, in adult bones, when periosteum would not produce new bone, this could be brought about by a stimulation of the dense bone by cutting and drilling, after which the periosteum left after resection would produce some new bone. Macewen, on the other hand, says that if bone is produced by a periosteal flap, this is due to the superficial layer of bone having been raised with it. Therefore, in reality, there is a middle or cambium layer lying between the bone and the periosteum in young animals. In such it is possible to raise the periosteum with the cambium layer attached, and it will reproduce the bone; or to dissect it off, without taking the deep tissue, and then it produces nothing.

d. In regard to free transplantat on of periosteum, there is less sharp divergence of results. For Ollier admits that bone formed from free periosteal transplantation becomes absorbed in a short time, whilst Macewen notes that a scanty bone growth is found in a periosteal flap taken from a limb and placed in the neck.

e. The behaviour of bone deprived of its periosteum. About this there is unanimity, and it is unfortunate that Ollier's own observations on this point should have been so much forgotten. He showed that the nude bone lived, grew in length and thickness, formed callus, and healed after fracture (obs. 14–17); also, that if the periosteum were removed, the bone beneath quickly re-formed a new periosteum, which had the same osteogenetic properties as the original (obs. 11–13).

f. The microscopic appearances after bone grafting. Axhausen has without doubt shown that after bone grafting the chief osteogenesis in the graft occurs beneath the periosteum. But it might equally well be stated that the new bone is formed from the superficial surface of the old bone as that it arises from the deep surface of the periosteum. It is exactly the old fallacy of crediting all superficial callus to the periosteum, when in reality it comes from the bone, as is proved by the fact that it is produced just as well if the periosteum has been removed. This point is so important that I here interpolate a preparation of my own, taken from a fractured cat's tibia after seventeen days (***Fig.* 130**). It shows an exuberant layer of superficial callus lying between the dense bone and the periosteum. In the process of cutting the section the soft callus has become detached from the hard bone, and remains attached to the periosteum, exactly in the same way as the inflammatory callus of an osteomyelitis, exuded from the bone, is split from it to form the involucrum. Nothing but the most superficial observation, however, could suggest that the callus in this specimen has come from the periosteum. It contains two well-marked stages, viz., the early cartilage and the late bone, and the former is becoming converted into the latter. But the bone callus is next to the bone, whilst the cartilage callus is next to the periosteum, showing that the original site of origin of the whole was from the bone, and that it was formed from within outwards, and not in the reverse direction.

It is unfortunate that the term 'periosteal' may equally well mean 'derived from the periosteum,' or simply indicate a position upon the outer surface of the bone. If throughout Axhausen's descriptions the term 'layer superficial to the bone' were substituted for the term 'periosteal,' it would be

equally accurate, and would be much fairer, as being free from the unproved assumption that the layer in question was derived from the membrane above it and not from the bone beneath it. In order to avoid this difficulty, and to escape from the use of the above phrase, I would suggest the use of the term

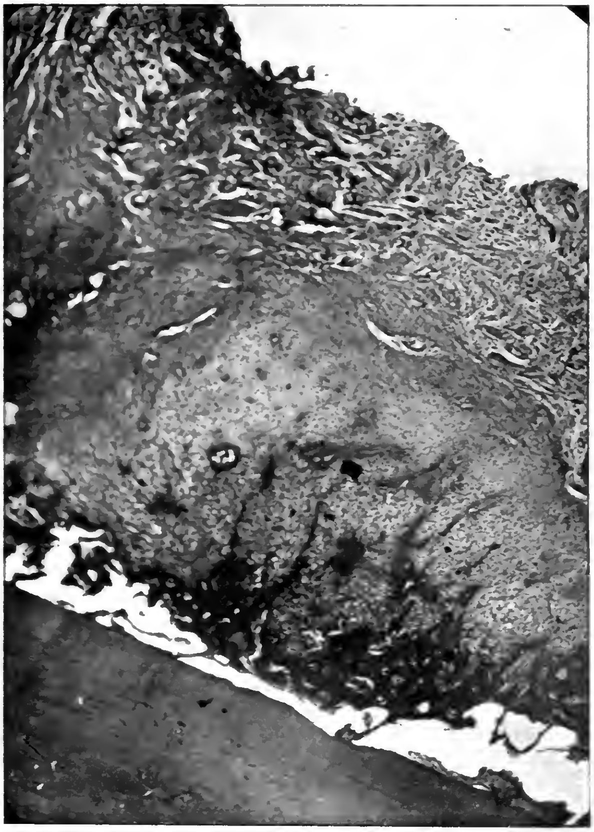


FIG. 130.—Cat's tibia, 17 days after operation. Longitudinal section of the dense bone, with the overlying external callus, as seen under a $\frac{1}{6}$-in. objective.

B, Dense bone of the shaft. S, Space between the callus and the dense bone, artificially produced in the cutting of the section. O.C, Deep layer of ossified callus. C.C, Outer layer of cartilaginous callus. P, Periosteum fused with overlying connective tissue.

There can be no doubt that this thick layer of external callus is growing in direct continuity with the bone, and the ossification proceeding from the bone. The way in which the callus breaks from the bone in the process of cutting the section, although purely accidental, is nevertheless very instructive, because it marks the line of most ready cleavage, between two layers of tissue of different density. When necrosis occurs, it is in this line of cleavage that the inflammatory products accumulate and separate the outer involucrum from the inner sequestrum. But, nevertheless, the involucrum has grown from the bone.

'episteal' to denote the structures on the surface of the bone beneath the periosteum. Axhausen proves the importance of the episteal bone layer, but he does not prove its origin from the periosteum.

g. The periosteum as a limiting membrane. All are agreed that the

periosteum is the bounding wall of bone, but it is also in some senses a limiting membrane, i.e., it limits and to some extent hinders bone growth. Macewen proves this (obs. 23, 24) by demonstrating the unrestrained exuberant growth which sometimes takes place after removal of the periosteum and a portion of the bone. This growth sometimes penetrated into the muscle layers surrounding the injured bone.

Axhausen's observations (obs. 9) confirm this in a different way. The epiosteal new bone formation was observed to be much more marked at the cut ends of the graft, and where the periosteum had been incised, than where the membrane was intact. At these points the epiosteum is relieved from the limiting action of the periosteum, and the bone-cells can be freely poured out, and grow.

b. The periosteum as a nutritive vascular membrane. There is no dispute about the fact that the bone receives its blood-supply partly through the vessels of the periosteum, and that when a part of the bone is separated from the rest, this constitutes for a time its sole blood-supply. Further, the surface of the periosteum readily becomes adherent to adjacent vascular structures, and becomes vascularized by them, in bone grafting; whereas a piece of nude bone offers the greatest possible resistance to the formation of new vessels, a process which cannot take place until it has been honeycombed by lacunar absorption.

Axhausen proved that grafts taken with their periosteum show a much greater viability and osteogenesis than nude grafts, and although he does not himself point out the possibility that this is due to the more ready vascularization, yet he relates facts which are very suggestive of this. Thus, he points out (obs. 8) that viability of the periosteum depends upon its coming into direct contact with vascular living tissues, and that if blood-effusion or adherent muscle intervenes between the periosteum and its bed, the former will die. He admits (obs. 5) that in some areas of even the dense bone of a graft, superficial portions show cells remaining alive. and this is just at points where the overlying periosteum has retained its vitality.

McWilliams (*vide infra*) has especially called attention to the importance of the periosteum on a graft in affording a ready means of establishing a new vascular connection with its bed.

Summary.—The periosteum is chiefly a limiting membrane of the bone. The dense bone can live, grow, undergo repair, and produce fresh periosteum after the latter has been removed.

In young bones it is possible to remove the periosteum in such a way as to produce an osteogenetic membrane, this being probably due to the lifting of the epiosteum with the periosteum. In adult bones this is impossible, except after trauma or inflammation. Nevertheless, the retention of the periosteum, though not necessary, is highly desirable in grafting, because its removal takes away much of the epiosteum, and because it affords a ready means whereby the graft may become vascularized.

2. **The Rôle of the Marrow Tissue.**—About the marrow tissue there has never been the same difference of opinion as about the periosteum, probably because its situation and structure are such that it cannot be removed

from the bone in such a way as to take an inner layer of bone cells with it. No one has suggested that marrow tissue can be used as a free graft with osteogenetic results.

Ollier showed (obs. 10) that a tube inserted into the marrow cavity became filled with new bone; and again (obs. 16), that if the periosteum is removed and a metal foil placed round the shaft of a bone, new bone will be laid down in the marrow cavity. In other words, the deep surface of the dense bone, like the superficial, is capable of osteogenesis under suitable stimulus—there is an endosteum as well as an epiosteum. Barth figured (obs. 5) new bone formation in the marrow spaces of bone grafts. Axhausen proved (obs. 2, 10) that in living grafts new bone is formed in that layer of the marrow tissue which is next to the bone, provided that this is closely in contact with vascular tissue of the bed. This will be at the cut end only of a graft of the whole thickness of the bone, or along the whole cut surface of a split bone. Macewen does not deal separately with the behaviour of the marrow tissue, but his glass-tube experiments (obs. 20–21) are somewhat similar to that of Ollier (obs. 10) mentioned above. In both the tube became filled with new bone tissue, though in Macewen's case this was derived partly from the compact bone. Therefore we have no difficulty in saying of the red marrow tissue, that its layers next to the bone (endosteum) have precisely the same capacity for osteogenesis as the epiosteum, though in a lesser degree. If grafted in such a manner as to allow rapid vascular connection with its bed, it will take an active share in new bone formation. In other words, a split graft will be more actively proliferative than a whole graft.

3. **The Rôle of the Compact Bone.**—As regards the behaviour of the compact bone, there are no conflicting facts. Ollier proved that, quite apart from both periosteum and marrow, compact bone could live and produce new bone and undergo the callus repair of a fracture. Macewen has further established these facts beyond all controversy. Barth, however, demonstrated that the great majority of cells in the compact tissue of a graft die, and Axhausen has abundantly confirmed this observation. But this fact does not warrant the conclusion that the whole of the compact bone of a graft always dies, and is nothing but a scaffolding—for the following reasons :—

a. Axhausen's own preparations in some cases show (obs. 5) areas at the edge of the compact bone where the cells retain their vitality.

b. Quite apart from the epiosteal and endosteal layers of cells which may be regarded as originating from the compact bone, Axhausen shows (obs. 7) that the widened Haversian canals contain active osteoblasts and new bone formation, and that the surface of the compact bone of the graft becomes pitted by lacunar absorption, and that in these excavations new bone is laid down. Now it cannot be proved either in the case of the osteoblasts in the widened Haversian canals or in those of the superficial erosions, that these cells have an origin outside the bone itself. On the contrary, it is much more reasonable to suppose that they are in part derived from the osteoblasts of the graft.

c. The behaviour of a bare bone in an open fracture is very instructive in this connection. The phenomena are well known, and yet the old fallacy of

bare bone being dead is still so widely held, in spite of Macewen's teaching, that it is, I think, worth while to emphasize it by an illustrative case.

Sergt. W. had a septic gunshot fracture of the lower third of his femur. In a large wound of the outer side of the thigh, the oblique ends of the bone were easily visible, and were at first perfectly bare on both medullary and periosteal aspects. I drilled both these fragments with many holes, about an eighth of an inch in diameter, on every accessible surface. Within a very short time the bare bone pushed out buttons of granulation tissue, and these spread until almost the whole surfaces were covered. I then gave an anæsthetic, levered the two fragments into apposition, and fixed them by two wire sutures. Eventually good union occurred, the granulation tissue having been converted into callus, with the loss of a small part of one fragment thrown off as a sequestrum.

Now in such a case, at a certain period the bones exhibit just such a 'lacunar absorption' as Axhausen demonstrates in his grafts. But my contention is that it is by a proliferation of the cells of the bone itself, and not of its surroundings, that this process takes place.

d. The behaviour of bone-grafts deprived both of periosteum and endosteum. There is no divergence here about the observation that such grafts can live and also grow. But there is a difference of opinion about the explanation of this, and a difference, too, about the degree of proliferation. Axhausen admits that nude bone-grafts live and proliferate (obs. 13), but he attributes this to the adherence of epiosteum and endosteum. He maintains that the chance of survival and the degree of proliferation are much less in such cases than in those where the periosteum and marrow are retained. In this he is confirmed by other observers, e.g., McWilliams and Phemister. Nevertheless, his admission of the potential viability of a bit of bare bone is of cardinal importance. Macewen, on the other hand, goes to the other extreme, and maintains that fragments of bone free from periosteum or marrow have a much greater osteogenetic capacity than a piece of entire bone. His observations (obs. 14, 15, 31) are concerned both with experimental and clinical investigations. It must be conceded that he has amply demonstrated the viability and the growth of bone chips, but his evidence does not entirely bear out his contention as to the greater osteogenesis in fragments than in a whole piece of bone. This is a matter of such great practical importance that it is necessary to examine it closely, and I shall return to it later in describing my own experiments.

Let us consider these experiments on the implantation of bone chips into a bone defect. Macewen removed the periosteum from the radius of two young dogs, resected a piece of the whole thickness of the bone, divided it into small chips, and implanted these into the gap, exchanging the bone fragments of the two dogs. In both cases, after seven weeks, the gap was filled with a large mass of bone, much thicker than the original piece removed. At first sight this appears to be conclusive evidence that the bone chips have undergone very great and rapid enlargement. But Macewen himself has taught us to beware of jumping to conclusions in matters concerning the origin of new bone. In examining figures of the specimens (*Figs.* 17, 18, 19, 20 in Macewen's book), with their measurements, two striking facts arrest the attention. First, the parts of the bone on each side of the gap have undergone great

thickening, i.e., they evidently have some share in the osteogenesis. Secondly, the length of both bones experimented upon is actually shorter by a quarter of an inch and five-sixteenths of an inch than the normal bone of the opposite side, and this at once suggests that there has been loss somewhere. If the two ends have grown, and the graft between them has grown, then the total produced should surely be longer and not shorter than normal. But in Macewen's later experiments (*Figs.* 42, 43), another dog's radius is shown in which a bit had been taken out together with the periosteum, and there, too, is the same filling of the gap with a spindle-shaped thickening, *although no chips had been inserted.* The explanation is now clear. A gap in the diaphysis of a young bone is filled by the double process of epiphyseal growth and proliferation from the cut ends, and if the periosteum is absent there may occur a spindle-shaped thickening in place of the gap. If the gap is filled with bone chips the same thickness of bone is produced, but there is no evidence that the chips have anything to do with the process.

In Macewen's classical case of the boy in whom he re-formed a humerus by successive implantation of chips from other children's tibias, there is also evidence on the one hand of the survival of the grafts, with consequent stimulation of the epiphyseal cartilages to proliferation, and on the other, of the stationary behaviour of the grafted material in the matter of size. That is to say, Macewen states that on three occasions he inserted bits of bone, each making up a length of about one and a half inches. Thirty years later the skiagrams clearly show the grafted part, and this is stated to measure four and a half inches. Thus, the fragments had lived, but there was none of that exuberant proliferation which would have greatly increased their bulk.

SUMMARY.—Compact bone, if it has a proper blood-supply, is quite independent of either periosteum or endosteum for both growth and repair If deprived of its blood-supply temporarily, as in a graft, it acts in a very indolent manner: the greater part of its cells die, but those on all the free surfaces—epiosteal, endosteal, and cut edges—survive, and proliferate to form new bone. The tissue becomes vascularized, and then in the new Haversian canals new bone is deposited. Fragmentation of a graft may secure the survival of a greater number of osteoblasts, but it does not ultimately produce a larger bone.

4. **Homoplastic and Heteroplastic Grafts.**—All observers have obtained success in the transplantation of bones or parts of bones from one individual to another of the same species. Axhausen demonstrated that the viability and proliferation of a homoplastic graft were more uncertain than those of an autoplastic. Heteroplastic grafts—i.e., bones transferred from one animal to another of a different species—become encapsuled or absorbed, and show neither vitality nor proliferative capacity. They may, however, act for an indefinite period as a splint or as a scaffolding for the laying down of new bone.

A SHORT NOTICE OF SOME OTHER IMPORTANT PAPERS.

In attempting to deal with the literature of bone-grafting, one is faced with the difficulty of the vast size of the subject. McWilliams,[5] for example, has compiled references to upwards of five hundred papers. Most of these, however, merely deal with isolated observations about human grafts, and

although they amplify and add details to our knowledge, they do not modify it in any essential respect. I propose, therefore, merely to select certain papers of special importance, without attempting any general epitome, this task having recently been accomplished with conspicuous success by McWilliams.

Four American papers represent recent work suggested by Macewen's book, and they deal with experiments done on the same lines.

Davis and Hunnicutt[9] repeated and confirmed Macewen's experiments. They showed that periosteum, either as a flap or as a free graft, did not produce bone, but if a thin layer of bone was raised with this membrane, osteogenesis occurred.

Brown and Brown,[10] too, obtained results similar to Macewen They added two important observations, viz.: (1) Living bone transplanted into soft tissue only survives for a short period, and ultimately undergoes absorption. This supplements and corrects the impression left by Axhausen's work. The latter author, concentrating his attention on the early microscopical changes in free bone-grafts, demonstrated cell proliferation and osteogenesis as above described. But this is only a transitory phase, and more protracted observations show that bone-grafts in soft tissue have only a fleeting existence. (2) Similarly, bone-grafts in contact with living bones, but performing no function, undergo atrophy. Both these facts are in unison with Wolff's Law, that the size of a bone is determined by the function which it has to perform.

Phemister[11] has published one of the most complete and carefully described series of experiments on this subject ever recorded. He removed about a third of the ulna in dogs, and replaced the graft into its bed under different conditions. These experiments demonstrated :

1. Actual osteogenesis occurring in the graft.
2. Osteogenesis occurring in a graft deprived both of its periosteum and endosteum. This was, however, much more scanty than that occurring in whole or split grafts.
3. The most marked osteogenesis always occurs in the region of the epiosteum and endosteum.
4. Of fragmented grafts many pieces die, but slow and scanty osteogenesis does occur round most of the separate pieces.
5. A fractured graft shows osteogenesis, i.e., callus formation, at the seat of fracture, and this is even more marked than the osteogenesis occurring between the ends of the graft and the mother bone.
6. Free periosteum does not produce bone.
7. Bone transplanted into soft tissues atrophies.
8. In a periosteal sleeve from which bone has been removed, then boiled and replaced, a cylinder of callus makes its appearance on the deep surface of the periosteum.

McWilliams[12] has recorded both human and animal results. In the former, several cases are noted in which a nude graft lived for a time and then became absorbed. One case is especially instructive—a fractured tibia in a child in which a nude graft failed (this was very small, and had poor contact with the bone ends). Afterwards a piece of the fibula was used with its periosteum. This was much larger, and had much better contact with the bones than in the case of the former graft. The fibula graft lived well, and grew in

thickness. It became fractured and underwent normal callus union. This osteogenetic callus formation in a fractured graft has often been observed, and recorded by Phemister, Robert Jones, and Küttner, among others, and it forms a convincing proof of the osteogenetic properties of a bone-graft.

McWilliams' experimental results demonstrated the practical importance of the periosteum. They showed that although nude grafts could live, yet they did so in a much smaller proportion than those transplanted with the periosteum. Split grafts also did better than whole ones. These observations confirm the importance of securing a ready blood-supply to the epiosteum and endosteum.

Läwen[13] gives a very detailed account of a human autoplastic graft, with some beautiful microscopical preparations. A boy, age 8, had the upper part of the humerus resected for a myeloma, and a piece of his tibia, covered on one side by periosteum, was substituted. Seventy-eight days later, amputation was performed for recurrence of the tumour. The specimen showed all the details described by Axhausen in his experimental work. The graft was richly vascular, but the bone-cells in the compact tissue had disappeared. Epiosteal and endosteal new bone was well marked, and there was extensive lacunar absorption of the dead bone, and new bone formation round the new vessels.

On the Grafting of Homoplastic Joint-ends.—Axhausen[14] has added to the work already described an important series of new experiments dealing with the transplantation of joint-ends of bones. Working with young rats and rabbits, he obtained functionally successful results. Bone tissue behaved similarly to that in his other experiments. The articular cartilage, after an initial stage of indolence, showed the superficial cells with good vitality, and the deep cells undergoing necrosis. Eventually the latter became substituted by the former, and the tissue as a whole remained active and vital. The epiphyseal cartilage mostly necrosed, only the superficial part remaining alive. The surviving part soon became ossified, and the rest underwent lacunar absorption.

Lexer[15] has had remarkable success in transplanting half or whole joints in the human subject. In a man with a myeloid growth of the upper end of the tibia, the head of the bone was removed, and substituted by a corresponding part of the bone from a recently amputated leg. Perfect functional success followed, but the limb had to be amputated eighteen months later on account of neurosis. But Lexer's classical case was that of a girl, age 18, in whom he resected the tuberculous knee-joint and replaced it by the joint from a recent amputation. The case was shown at the German Surgical Congress, and nearly two years later the patient could walk well with a stick, and had free movement in the joint.

He makes the following general observations as the result of his work. The joint should be exposed by a broad flap incision so as to avoid a suture line over the graft. Accurate hæmostasis is essential, as any blood collection will prevent union of the graft with its surroundings; and it is better to avoid the use of a tourniquet because of the liability to subsequent oozing. It is of great importance that the bone ends should fit accurately, but he avoids the use of any foreign body for the purpose of fixation. If such is necessary, he uses fresh autogenous bone pegs. Joints taken from freshly amputated limbs, or

those from corpses taken within twenty-four hours of death, may be used. All tendons, muscle, fat, and ligaments must be removed from the graft, and the periosteum divided by longitudinal incisions. He is uncertain whether the best success will be given by retention or removal of the synovial membrane, the evidence on this point being conflicting. If an important muscle-tendon group has been destroyed, e.g., that of the quadriceps and patella over the knee, it is best to wait until the main graft has healed, and then to do a new tendon-grafting. The later history of joint transplantation shows a stage of grating like that of rheumatoid arthritis, but movement is free and painless, and the grating becomes less with use.

Küttner,[16] too, has had great success with homoplastic transplantation of joint-ends in two instances. Particulars of his cases are added.

Case 1.—Patient had the upper end of the femur removed for sarcoma, and a bone taken from a corpse, thirty-five hours after death, was used to replace the lost portion. He had excellent use of the leg, but died thirteen months later of metastatic growths. To the naked eye the specimen showed neither necrosis nor absorption. Sound callus union had occurred between the graft and its bed. It was very remarkable how firmly the muscles had acquired a normal attachment to the graft. Microscopical facts revealed were: the survival of the articular cartilage, the absence of cells from the compact bone, and the presence of an epiosteal layer of new bone and of some lacunar substitution at the point of junction with the main bone.

Case 2.—The upper third of the femur was removed for sarcoma, and a graft was taken from a corpse, three hours after death. It was adjusted with the help of an intramedullary fibular graft, also taken from the corpse. Later on a fracture of the graft occurred, and this healed by natural callus. Finally, amputation had to be done on account of recurrence. Examination showed the same points as in *Case* 1, viz., firm attachment of muscle to the graft, retained articular cartilage, loss of the cells in the compact tissue, and early substitution by the surrounding tissues.

Case 3.—A child with congenital absence of the fibula had a fibula grafted from the leg of a Java ape. This remained *in situ* for nearly two years, but the *x*-ray picture gives no suggestion of any growth or function.

On the Use of Dead bone-grafts.—The use of sterilized bone or ivory for filling bone defects has often been employed, and although since the knowledge of the possibilities of living grafts it has fallen into the background, yet it is a subject of practical importance which we cannot afford to ignore. For the present purpose it will be sufficient to refer to König's work as illustrative of this branch of the subject.

König[17] has used ivory intramedullary pegs and periosteal ivory plates for the operative treatment of fractures. Encouraged by the results of these cases, he had ivory models made of various parts of the bones, and these he has used several times to replace parts lost by injury or disease—e.g., half the lower end of the humerus in one case, and two cases of half the lower jaw. In all of these smooth healing occurred in the first place, but in several a purulent sinus developed after several months or years, necessitating the removal of the foreign body. His most remarkable case was that of a woman, age 62, in whom the half mandible was replaced by an ivory prothesis. It not only healed quite smoothly, but became firmly attached to the remaining half of the jaw, whilst articulating freely in the temporal joint. She was shown at the

German Surgical Congress, and at the time of the report, two years after the operation, the result appeared to be perfectly satisfactory.

If an ivory peg heals with perfect asepsis, it quickly becomes pitted and roughened by ingrowth of surrounding granulation tissue. By this means it is incorporated with the structures of its bed. If, on the other hand, sepsis occurs, the graft may remain in position for an indefinite period, but it never is really attached to its surroundings, and when removed its surface is perfectly smooth.

Barth's work has familiarized us with the idea that dead bone and ivory may, under favourable circumstances, heal with the tissues and become incorporated by them, being substituted by connective tissue, or by bone if osseous tissue is ready at hand.

It may be demonstrated by the *x* rays that ivory pegs become completely absorbed in a period of one to ten years. Stieda[18] gives a good illustration of this. A girl, age ten, with a congenital fracture of the tibia, with pseudo-arthrosis, had had several operations without success. Then two stout pieces of boiled tibia from an amputated limb were fixed round the fractured area, and consolidation occurred. Eleven years later the bone was thick and firm, and not the slightest trace of the bone-plates can be seen in the skiagram.

The question then arises whether it is reasonable or consistent to imagine that dead-bone pegs will become absorbed under one set of circumstances, and yet remain indefinitely as a permanent skeletal structure in another. It is unfortunate that König gives no *x*-ray pictures of his cases to clear up this point. In his best case only two years had elapsed since the massive piece of ivory had been inserted. It is quite possible that small pieces of dead bone may become absorbed, whilst large ones remain. In the latter case, a certain depth of the outer part of the graft will be eaten into and substituted by connective tissue, whilst the central mass will remain. The same thing is seen in connection with the absorption of dead bone resulting from sepsis. Small particles are eroded and eaten up by granulation tissue, but large pieces will remain as sequestra for an indefinite period.

Albee's work[19] has been almost entirely of a practical character. By a great improvement in operative technique, he has placed the subject of bone-grafting upon the footing of a regular surgical procedure, the indications for which appear to be more frequent every day. His pioneer work lay in the introduction of a method of bone-grafting for Pott's disease of the spine. He split the spinous processes of several vertebræ above, below, and including the affected area, and then sewed in a piece of the inner surface of the shaft of the tibia. The cases in which this operation has been done are now several hundreds, and the results are said to be very satisfactory. But his precise method of laying in bone-grafts in order to unite fractures and to make good defects in the long bones constitute the most valuable part of his work. Inasmuch as the novelty of Albee's work chiefly relates to matters of technique, and not to the principles of bone-grafting, it will be more convenient to postpone a critical examination of it until a later part of the present paper.

Lindemann[20] has recently published a long series of cases of bone-grafting for fractured jaws; this deserves special mention, because of the importance

of this branch of the subject, and because there are so few publications which deal with more than one or two isolated cases.

In the first place, he attaches cardinal importance to a proper immobilization of the jaw by suitable splints, and to a proper closure of any defect in the soft parts, by a plastic operation if necessary. Any sepsis evident before the operation, or discovered during its early stages, should lead to the postponement of the bone-grafting. The jaw is exposed by an external incision, and on no account must the oral cavity be opened. The ends of the jaw fragments are exposed, and bared of connective tissue. Then an opening is made into the marrow cavity of each. Next a piece of the inner surface of the tibia is taken of suitable length, and its ends are fashioned into peg-shaped processes to fit into the holes of the jaw fragments. In this manner Lindemann has implanted grafts varying in length from $1\frac{1}{2}$ up to 13 cm. In the great majority the graft measured $2\frac{1}{2}$ cm. He recounts 97 cases; primary union occurred in 86, and 51 of these obtained firm bone union, whilst in many others consolidation was in progress.

The Cultivation of Bone-tissue in Vitro.—One other aspect of the question of bone-grafting requires mention. Living bone tissue can be cultivated *in vitro*, and the resulting phenomena have an important bearing on the problem of the survival of grafts and on the rôle of the different tissues.

Dobrowolskaja[21] has carried out this work. Small pieces of bone were taken from young animals (mice, kittens, rabbits), placed on slides in homogenous plasma, and covered with a watch-glass with a hanging drop of distilled water, the cell being hermetically sealed with paraffin. The preparation was placed in the incubator. When whole pieces of bone were used with periosteum and marrow attached, such a luxuriant cell growth occurred, accompanied by intense round-cell infiltration, as to obscure details of the growth. When small pieces of bone were cultivated without either periosteum or marrow, a definite and clear growth of bone-cells occurred, free from round-celled infiltration. Different forms of cells were seen, with processes growing out from the compact bone. Sometimes, if two pieces of bone were close to one another, the space between them was rapidly filled by growing cells, which united the two parts. Cultivation of periosteum, on the other hand, even in young animals, produced hardly any growth. Pieces of spongy bone containing marrow tissue gave rise to an active growth in which round-celled infiltration predominated.

On the Use of Pedicled Bone-grafts.—Until recent years, the possibility of free transplantation of bone was not generally recognized, and when a bone-graft was performed, a flap of skin and connective tissue was raised with an underlying piece of bone, and sewn into the defect. In this way an adequate blood-supply to the bone-graft was secured, and many brilliant results were achieved.

The most frequently performed of these operations have been as follows: (1) Formation of a new nose: by taking a forehead flap containing a part of the frontal bone, or a flap from the forearm containing a piece of the ulna, or a finger with its phalanx, and other still more complicated processes. (2) Filling defects in the lower jaw: by taking a chest flap containing a section of the clavicle or a rib, or a flap from an adjacent part of the face with a bit of the underlying jaw-bone. (3) Gaps in the tibia have often been made good by a flap from the opposite shin containing a part of the crest of the tibia;

in some cases a flap from the same leg containing a piece of the fibula has been used with success. (4) Gaps in the humerus: filled by a chest flap with a bit of rib, or a flap from the shoulder containing the spine of the scapula. (5) Gaps in the femur: filled by a flap from the same thigh containing a piece of the femur, or a flap from the buttock with the crest of the ilium. For details regarding the technique of these operations and the authorities who have used them, I would refer the reader to McWilliams' "Collective Review."

In general terms it may be said that these elaborate pedicle operations are almost obsolete. They all involve very grave disadvantages: the operation itself is usually one of considerable difficulty; it often necessitates several operations; it leaves a large gap in the part from which the flap is taken to be filled in by further plastic procedure: and, most important of all, it is a type of operation which temporarily leaves open the tissues, and therefore asepsis is impossible. There are two possible advantages to be placed against all these drawbacks. A well-nourished flap with a good pedicle can be implanted in a granulating surface with better prospects of healing than will be afforded by a free graft. Secondly, such a flap will serve to fill up a gap left in the soft tissues as well as the defect in the bone. Probably, however, it is better to deal with the soft tissues and the bone separately, first making good the former by a suitable plastic operation, and then, when sound healing has occurred, implanting a free bone-graft.

II. ORIGINAL EXPERIMENTAL OBSERVATIONS.

A consideration of the work already done on the subject of bone-grafting has convinced me that, so far as the biological aspect is concerned, the main facts, as already set out, are well established. My own experiments, therefore, have been directed chiefly to a determination of practical conclusions having a direct bearing upon the best methods of transplanting bone-tissue so as to make good defects left by trauma or disease.

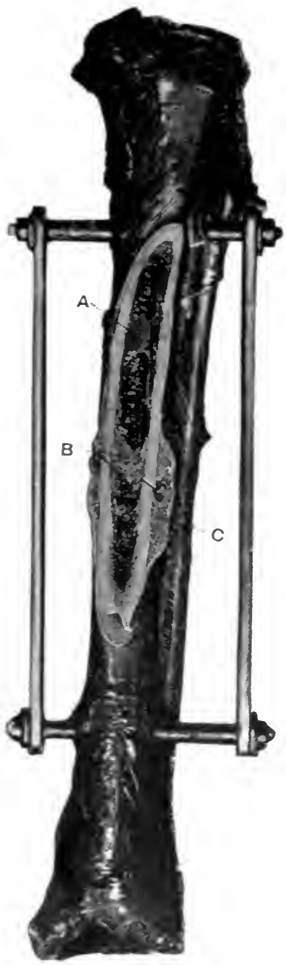


Fig. 131.—Cat's tibia, 14 days after fracture, with double-transfixion apparatus. A, Islet of cartilage present in the medulla far from the fracture. B, Internal callus, present only in the upper fragment. C, External callus.

The experiments have been performed on adult cats, using chiefly the tibia and the femur. In order to overcome the difficulty of immobilization of the limb, I have used, when necessary, a double-transfixion splint for the tibia. This consists of two rods which transfix the bone at its upper and lower ends, the extremities of the rods being fixed by screw-nuts into longitudinal steel bars which lie outside the limb on either side (*Fig.* 131). This apparatus not only serves to keep the bones

in place, but it also secures the dressing so that the animal cannot lick its wound during the early stages of healing.

A bone defect, however caused, may be made good in various ways, as shown in the following scheme.

SOURCES OF GRAFT.—

Living.—From the same individual—autogenous.
From another individual of the same species—homogenous.
From an animal of another species—heterogenous.

Dead.—Sterilized bone or ivory.

STRUCTURE OF LIVING GRAFTS.—

With periosteum and marrow—entire.
Without periosteum, with marrow.
Without periosteum or marrow—nude.
Coarsely fragmented.
Reduced to dust.

MANNER OF THE FIXATION OF THE GRAFT.—

A graft of the whole thickness of the bone placed end to end in apposition with the fragments of the bed.

A graft of the half thickness of the bone mortised to its bed.

Suture: (*a*) Not employed: (*b*) Of absorbable material, e.g., catgut; (*c*) Of non-absorbable material, e.g., wire; (*d*) By bolts and screws, etc.

From a practical point of view, the relative advantages of these different methods of grafting have to some extent already been settled.

Thus, the following may be taken as already proved :—

1. Living grafts are better than dead.
2. Autogenous grafts are better than homogenous.
3. Homogenous grafts are better than heterogenous.

The following propositions are based upon sufficient weight of evidence to cause them to be generally adopted as rules of practice :—

1. A graft provided with periosteum and endosteum will more surely live and more quickly grow than a nude graft.
2. In conditions where a bone defect cannot be replaced by an autogenous graft, i.e., a complicated articular surface, the use of a homogenous graft taken from a recent amputation or a corpse is indicated.

The following are questions to which there are no uniformly accepted answers founded upon definite evidence :—

1. If a graft can be secured of the full thickness of the bone which has to be mended, is it better to use the whole of the graft or to split it?
2. If a graft cannot be provided of the same bulk as the bone it has to replace, will it be better to use the graft as a single piece or to break it up into fragments?
3. Can living bone be reduced to dust in such a way as to form a living plastic material?

4. Supposing that enough living bone can be secured to use either method, does cortical or medullary grafting give the better result ?
5. In relation to the bone contact of the graft with its bed, are (*a*) The extent of the contact ; (*b*) Accuracy of apposition matters of importance ?
6. Ought a graft to be firmly fixed to its bed, or is temporary suture by animal membrane sufficient ?
7. What is the effect of metal sutures, e.g., wires, screws, or bolts, upon the grafting process ?
8. Has living bone any advantage over dead for grafts of a temporary purpose, e.g., pegs ?
9. Is absolute prolonged immobilization of the limb necessary in bone-grafting; or, if not necessary, is it beneficial ?

The following series of experiments is a contribution to the evidence necessary for answering the questions involved in the last nine propositions.

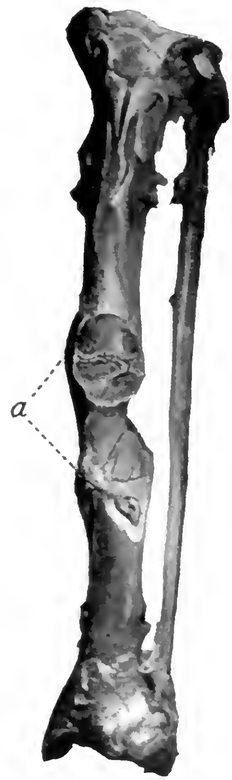


FIG. 132. — *Experiment* 1. Cat's tibia after a portion has been removed and replaced as a graft. *a*, Graft. At both points of junction of the graft with the bone, a superficial portion has been cut away to show the line of union.

A.—CORTICAL GRAFTS.

Experiment 1 (*Fig.* 132).—**Grafting the Whole Thickness of a Portion of Bone.**—From an adult cat a piece of the left tibia was removed subperiosteally, and then replaced, merely reversing the ends so that the proximal end of the graft lay against the distal end of the bone, and vice versa. The limb was immobilized by transfixion. Healing was primary, and the animal was killed in six weeks.

The specimen shows firm and accurate bony union between the graft and its bed at each end. There is marked thickening of the graft at each extremity. That this is not merely due to a deposit of new periosteal bone, or to a growth over the graft from its bed, is shown by the fact that the graft is altered interstitially so as to present an open spongy texture. The central portion of the graft represents the original thickness of the bone, and it will be seen that both ends of the original shaft have become thickened for some distance from the lines of union with the graft.

This experiment shows how well a whole-thickness graft grows into place, and how quickly and perfectly it will be able to functionate. No suturing is required to fix it, because with proper splinting there is no tendency to displacement. The layers of the graft are firmly in contact with the corresponding layers of the bed, and there is perfect mechanical stability, without the necessity for the filling up of gaps or the absorption of unnecessary

structures. In fact, when such a graft is in place, we have practically a double fracture of the bone in perfect position, without loss either of form or substance.

It is evident, however, that this ideal type of autogenous graft can seldom be employed clinically, because it is impossible to get a graft from the patient of the same size and shape as the lost part. The use of a portion of the shaft of the fibula for a defect in the forearm bones is the only clinical instance where this method can be followed. It is therefore necessary to turn our attention to methods of using grafts from a portion of the thickness of the bone.

Experiments 2, 3, 4.—**Cortical Grafting of a Portion of the Thickness of the Shaft, there being a Fracture but no Gap in the Bone to be Mended.**—A piece of the front of the tibia about one inch long was cut out, taking a little less than one-half of the thickness of the bone. The rest of the shaft was now divided at about the middle of the area from which this part had been taken. The graft was then re-applied, reversing the ends, so that it should not exactly lie in its original position. It was fixed by four wire sutures, placed in the manner indicated in the diagram (*Fig.* 133). No transfixion or any restrictive apparatus was used.

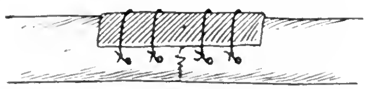


FIG. 133.—Diagram of graft fixed by four wire sutures passing through the bone ends.

In all these experiments primary smooth healing occurred, and *Figs.* 134, 135, 136 represent the results after four, six, and eight weeks. It will not be necessary to describe each of these in detail, as the main features are the same. The alinement has been perfectly maintained, and union is just like that in a subperiosteal comminuted fracture. In *Experiment* 2 (*Fig.* 134) the graft has fully united to its bed at one end only. In *Experiments* 3 and 4 (*Figs.* 135, 136) the union is complete, whilst in the former (*Fig.* 135) the thickening undergone by the graft itself is very manifest.

In these experiments the graft acted as an immobilizing splint, and there was no external fixation, nor any restriction of the animal's movements. Metal sutures, however, were employed which firmly attached the bone to the graft, and these served to secure immobility. There is no evidence that these metal sutures exercised any inhibitory influence upon the process of repair.

This method of grafting half the thickness of the bone as a cortical graft, then, gives ideal results. It represents a method of treating fractures by the use of a living-bone graft instead of a metal plate, and if the graft is sufficiently stout, and is properly fixed, it will give good results with much greater certainty, because the graft rapidly becomes organically united to the bone.

Experiments 5, 6, 7 (*Figs.* 137, 138, 139, 140, 141)—**Cortical Graft of Half the Thickness of the Shaft, there being an Actual Gap in the Bony Bed.**—Half the thickness in the front of the tibia was removed for one inch, and from the remaining part of the shaft the middle third was taken away altogether. The anterior portion was then reversed and fixed in the gap. The leg was immobilized by the double-transfixion apparatus.

In *Experiment* 5 (*Fig.* 137) the graft was fixed by wire sutures. There is perfect position, but very little macroscopical evidence of new bone formation,

either from the graft or its bed. *Fig.* 140 shows the new bone joining the graft to the bed.

In *Experiments* 6 and 7 (*Figs.* 138, 139) the graft has been fixed by split pins and washers, and in both these there is very perfect bone union between the graft and its bed.

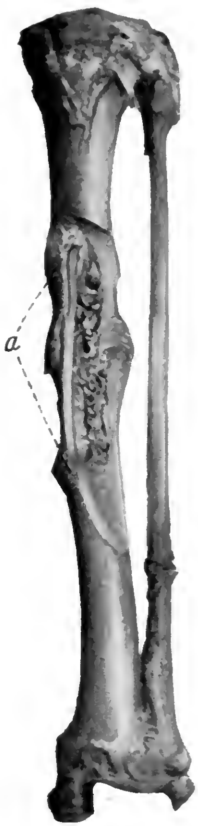


FIG. 134.

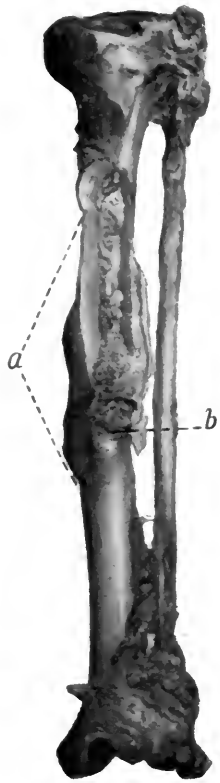


FIG. 135.

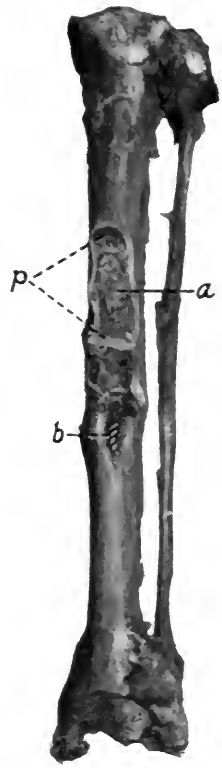


FIG. 136.

FIG. 134.—*Experiment* 2. A cortical graft of half the thickness of the tibia. After 4 weeks. *a*, Graft.

The shaft has been cut down through the middle of the graft. At the lower end bony union has occurred between the graft and its bed ; at the upper end the two are still distinct.

FIG. 135.—*Experiment* 3. Cortical graft of half the thickness of the tibia. After 6 weeks. *a*, Graft. *b*, One of the suture wires almost buried.

The shaft is cut down through the length of the graft. Both ends are firmly united to the bed ; the graft has increased in thickness.

FIG. 136.—*Experiment* 4. Cortical graft of half the thickness of the tibia. After 8 weeks. *p*, Piece of the shaft cut out to show the junction between the graft and its bed. *a*, Line of junction. *b*, One suture wire.

There is perfect restoration of the bone.

The conditions of these experiments represent very nearly what is commonly found after gunshot fractures with loss of bone, except that in clinical practice the graft would generally have to be taken from another bone than

that injured. Here again it may be remarked that there is no evidence of the metal sutures or pins interfering with the process of bone repair.

Fig. 140 is a microphotograph from *Experiment* 5, and *Fig.* 141 from *Experiment* 6, showing the layer of new bone between the graft and its bed, with well-marked lacunar erosion of both bones.

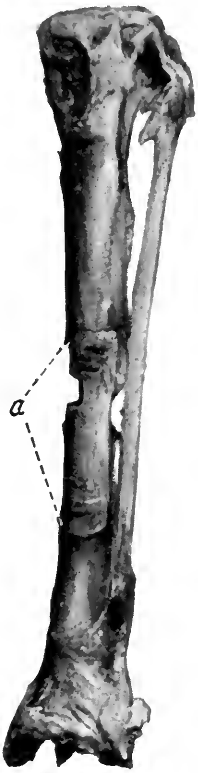


FIG. 137.

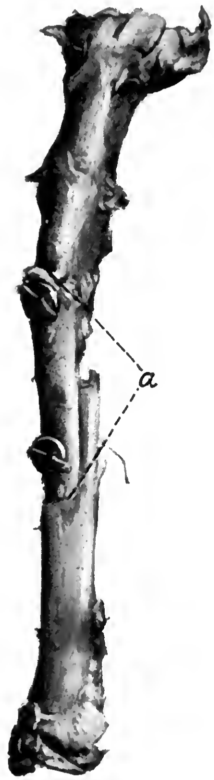


FIG. 138.

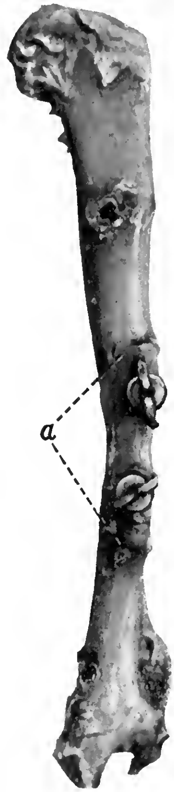


FIG. 139.

FIG. 137.—*Experiment* 5. A cortical graft of half the thickness of the shaft, with a gap in the remainder of the bone. After 6 weeks. *a*, Graft, which has been fixed by four wire sutures.

There is no evidence of new bone formation, except at the edges of the gap.

FIG. 138.—*Experiment* 6. Cortical graft of half the thickness of the tibia, with a gap in the shaft. *a*, Graft, fixed by split pins.

FIG. 139.—*Experiment* 7. Autogenous cortical graft, fixed by split pins. After 6 weeks. *a*, Graft.

B.—INTRAMEDULLARY GRAFTS.

The simplicity of the technique involved in the placing of a short bone peg into the marrow cavity of the fragments of a long bone from which there has been some loss of substance, has made this a very common practice in the treatment of ununited fractures.

It will be sufficient to describe and figure four experiments illustrating this procedure. In all of these a piece of the whole thickness of the left tibia was removed, and a graft was taken from the crest of the right tibia and

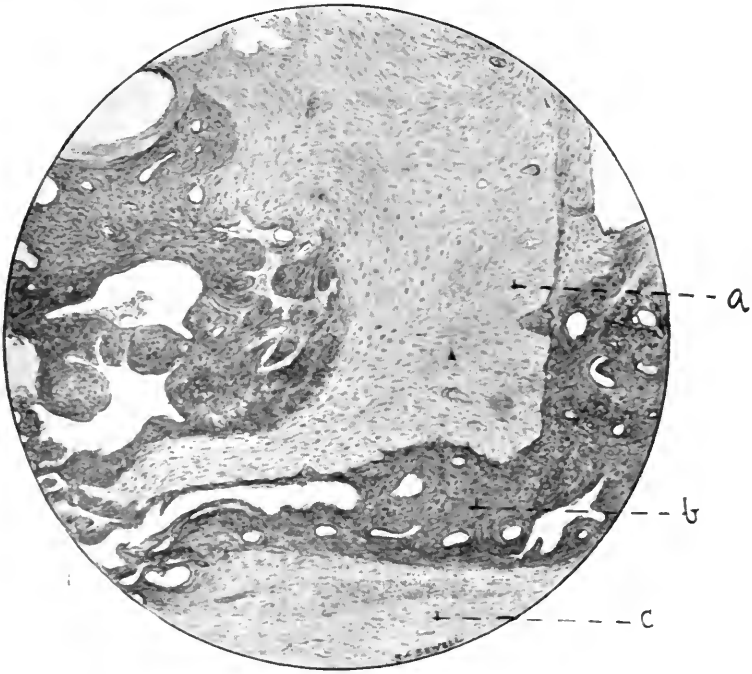


FIG. 140.—*Experiment* 5. *a*. Graft. *b*, New bone joining graft to bed. *c*, Bone bed.

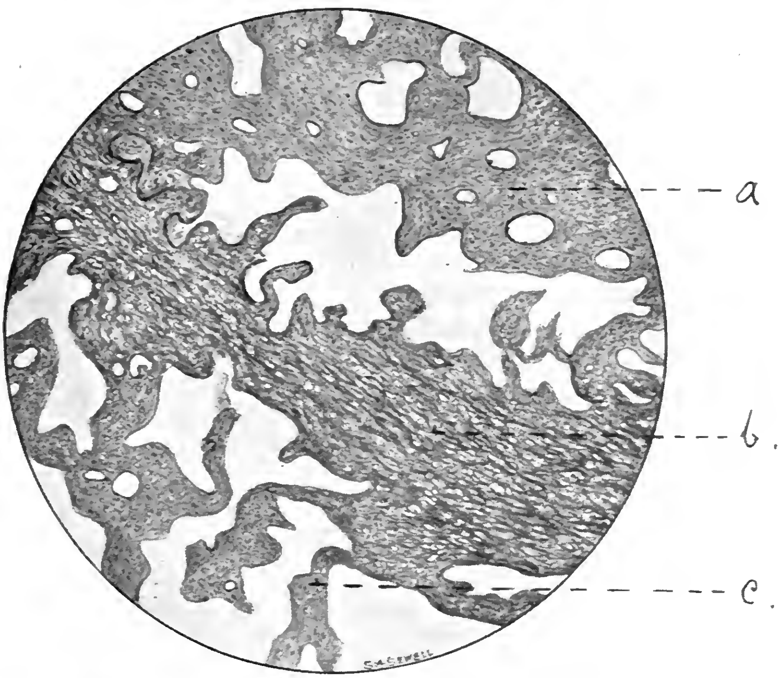


FIG. 141.—*Experiment* 6. *a*. Graft. *b*, Fibrocartilage joining graft to bed. *c* Bone bed.

employed as an intramedullary peg. The left, i.e., the divided tibia, was supported by a transfixion apparatus. All the cats were killed after six weeks.

Experiment 8 (*Fig.* 142).—In this the graft, which fitted well, had broken, and the fibula also was fractured. This latter accident must have occurred just before the animal was killed, as there is no evidence of repair. Both portions of the graft have grown firmly into the ends of the tibia, which shows scanty callus.

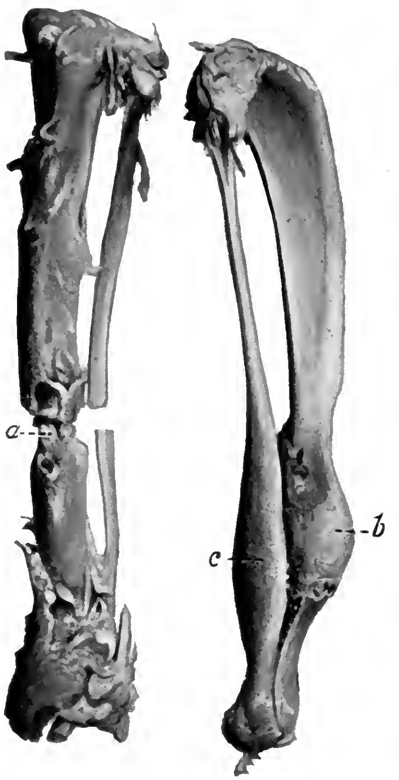


Fig. 142.—*Experiment* 8. Killed after 6 weeks.

Left side.—*a*, Intramedullary graft, broken above; firmly grown into ends of fragments, but forming very little new bone.

Right side.—The graft has been taken from the tibia. The bone has partly fractured, and undergone great callus thickening. The fibula has greatly hypertrophied. *b*, Tibial callus. *c*, Area of fibular hypertrophy.

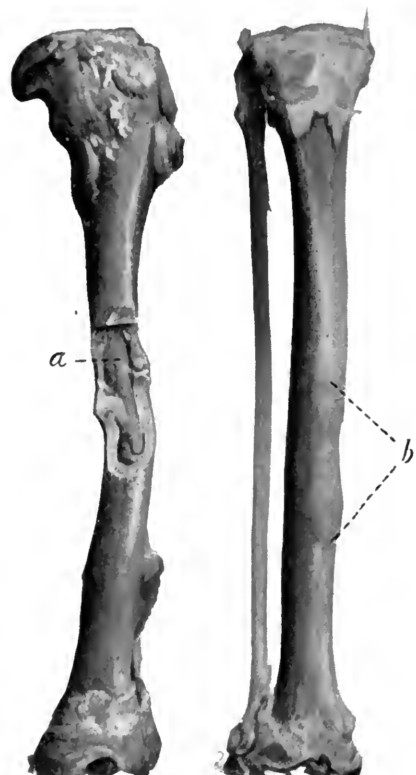


Fig. 143.—*Experiment* 9. Killed after 6 weeks.

Left tibia.—*a*, Intramedullary graft. The gap in the bone is filled by soft callus.

Right tibia.—The graft was taken from this side. *b*, The area from which a piece of bone was sawn, perfectly filled by new bone.

The right leg bones, which also are figured, demonstrate two interesting points. The tibia from which the graft was taken has undergone a partial fracture, which, being unsupported by any apparatus, has been subject to considerable mobility, with the result that a much larger mass of new bone has formed than that removed for the graft. The fibula, too, having to act as a splint to the broken tibia, has undergone a very marked hypertrophy. The

contrast between the presence of large masses of new bone on the right side and its absence on the left is a striking evidence of the influence of good blood-supply and free mobility in the promotion of osteogenesis.

Experiment 9 (*Figs.* 143, 144).—In this the medullary peg was much looser; but, on the other hand, much more callus has been thrown out by the bone ends, enough in fact to fill the gap. The peg lies in the midst of this intramedullary callus, and the microphotograph (*Fig.* 144) shows that the dense bone of the graft is opened up by lacunar absorption and the callus is insinuating itself into it. The evidence of this specimen is that the bone-graft is playing a purely passive rôle, acting neither as a splint nor as an osteogenetic

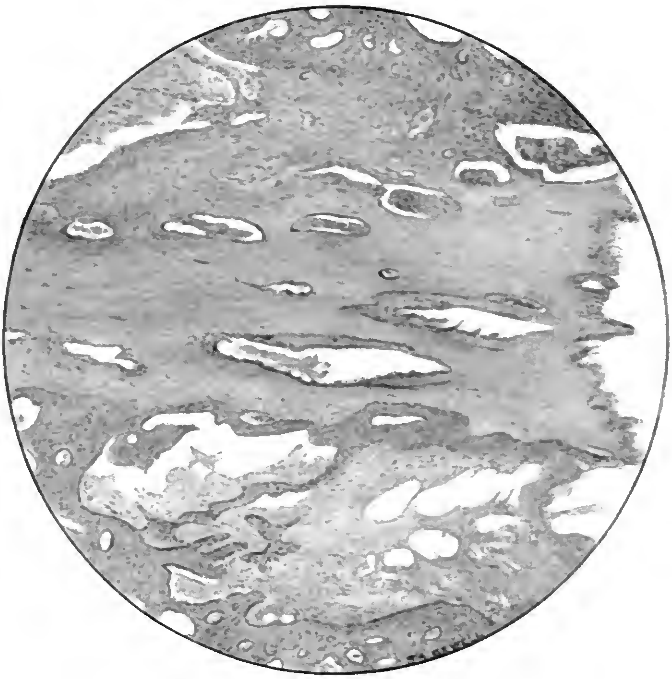


Fig. 144.—*Experiment* 9. Intramedullary graft undergoing lacunar absorption

centre. The tibia on the right side, from which the graft was taken, shows the perfect restitution which has occurred, the gap made by cutting the graft being filled up.

Experiment 9*a*.—This was performed some years ago, but the illustrative figures are here put in because they show exactly the same features as those of the last case (*Figs.* 145, 146).

Experiment 10 (*Fig.* 147).—In this the graft was made to fit tightly. It broke, however, at the point where it entered the upper fragment. The manner in which the intramedullary fragment is firmly fixed is shown by the figure. The endosteal callus is growing into the peg.

Experiment 11 (*Fig.* 148).—In this the peg was fitted as tightly as possible. It has become firmly fixed in place, but there is no new bone formed to fill the gap, and the peg has broken.

This series of experiments shows very clearly that intramedullary pegging with live grafts is of very little value as a method of inducing osteogenesis. If the graft fits tightly, it is very apt to break; and apart from this serious drawback, the tight plug in the marrow cavity of each fragment prevents the outgrowth of callus from this situation. In *Experiments* 9 and 9*a*, in which the graft lay loose in the marrow cavity, callus had been poured out in sufficient quantity to fill the bone gap, but in all the rest, where the graft acted as a plug, there was a conspicuous absence of callus repair. An intramedullary peg is a very inefficient mechanical method of bridging a bone gap. The size of the peg makes it too weak to act as a splint, and if it is fitted tightly it is snapped off by the slightest strain. The graft acts in a very passive manner, so that in no single instance could any evidence be seen of new bone growing from the graft.

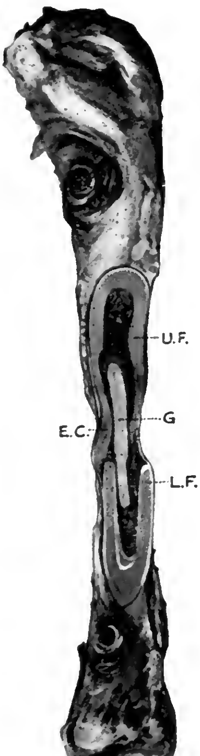


FIG. 145.

FIG. 146.

FIG. 145.—*Experiment* 9*a*. After 49 days. A graft from the opposite leg lies firmly growing into the ends of the bone and surrounded by a cartilaginous callus. U.F, Upper fragment. L.F, Lower fragment. E.C, External callus. G, Bone graft.

FIG. 146. *Experiment* 9*a*.—Skiagram of cat's tibia shown in *Fig.* 145.

FIG. 147.—*Experiment* 10. The upper part of the left tibia, with bone-graft as an intramedullary peg. *a*, The peg, which has broken below; the union was therefore a failure.

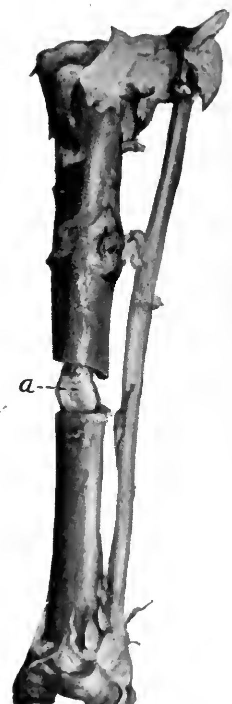


FIG. 148. — *Experiment* 11. After 6 weeks. *a*, Intramedullary bone-graft.

Firm union has occurred, but no new bone formation. The graft has fractured.

C.—The Influence of Fragmentation on the Growth of a Graft.

Experiments 12*a*, 12*b*, 12*c*.—Some years ago, when experimenting upon the methods of fracture repair, I was greatly surprised to find that if a portion of one of the long bones was removed, broken up into small pieces, and replaced,

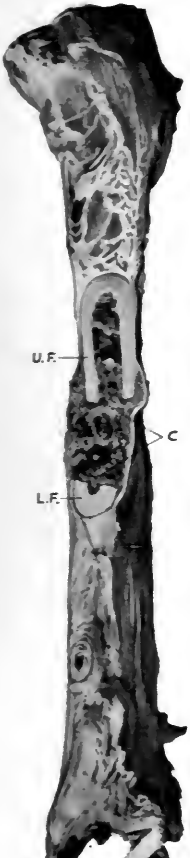


Fig. 149.

Fig. 150.

Fig. 149.—*Experiment* 12*a*. Grafting bone fragments. After 15 days. The grafted bone chips lie embedded in early callus. U.F. Upper fragment. L.F. Lower fragment. C. Callus with loose bone chips.

Fig. 150.—*Experiment* 12*a*. Skiagram of tibia illustrated in *Fig.* 149, showing separate fragments.

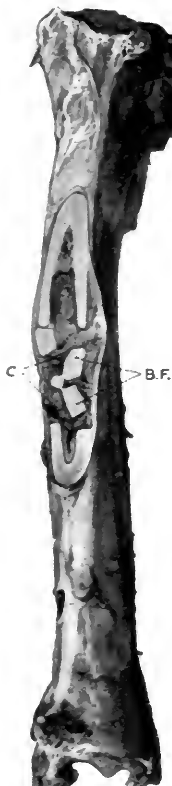


Fig. 151.

Fig. 152.

Fig. 151.—*Experiment* 12*b*. Grafting bone fragments. After 70 days. Except that the callus is cartilaginous, there is not much advance over the 15-day specimen shown in *Fig.* 149, many of the chips being still quite distinct. C. Callus. B.F. Bone fragments.

Fig. 152.—*Experiment* 12*b*. Skiagram of tibia shown in *Fig.* 151. The chips are still quite discrete.

very little new bone-formation took place. This is in great contrast to what occurs after a comminuted fracture. These experiments are illustrated in *Figs.* 149, 150, 151, 152, and 153. At the time, I thought that the phenomena must have been exceptional, because one would have expected the divided

bone to have made much new bone, each bit forming an osteogenetic centre; in fact Macewen has made this statement, and his dictum has been accepted by many. I have repeated these experiments, and give the results below.

Experiment 12 (*Fig.* 154).—A piece of the left tibia was removed and split up into as small pieces as possible by crushing, and then replaced. After six weeks the pieces of bone are still quite distinct, and not even firmly united to one another or to either main fragment.

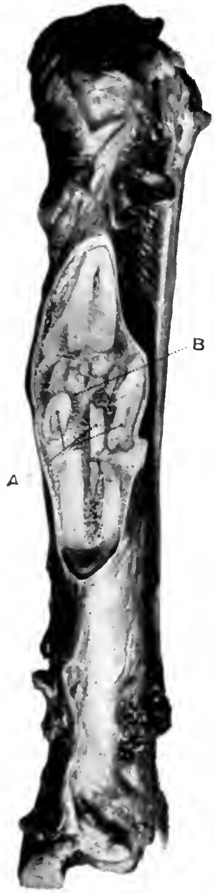


FIG. 153.

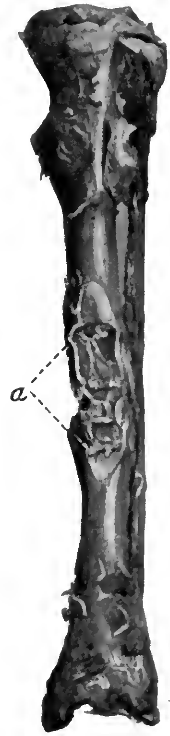


FIG. 154.

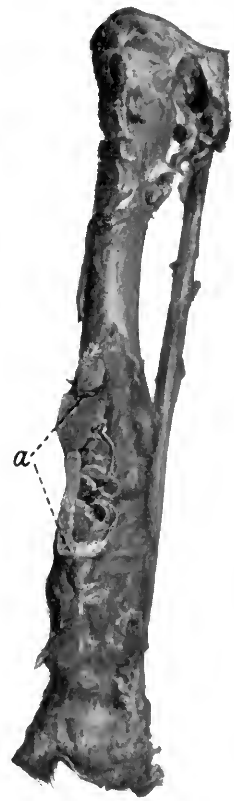


FIG. 155.

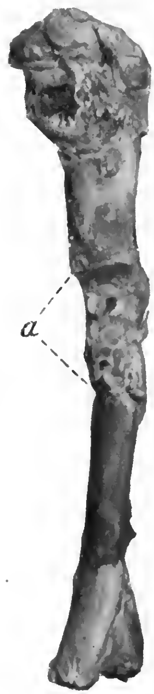


FIG. 156.

FIG. 153.—*Experiment* 12c. Comminuted fracture. Fragments left *in situ*. After 8 days. A, Small fragments of bone. B, Callus growing from these fragments.
Contrast the behaviour with that of the bone chips removed and replaced shown in *Figs.* 149, 151.

FIG. 154.—*Experiment* 12. Piece removed from tibia, fragmented, and replaced. After 6 weeks. *a*, Broken-up portion.
Note the indolence of the bits of bone, and the absence of new bone growth.

FIG. 155.—*Experiment* 13. Graft broken up into small bits. *a*, Fragmented portion, exposed by a saw-cut, which has broken out some of the pieces.
The lower fragment has become inflamed, and has formed periosteal new bone, which has partly ensheathed the indolent fragments.

FIG. 156.—*Experiment* 14. After 6 weeks. *a*, Fragmented graft. No new bone.

Experiment 13 (*Fig.* 155).—The same as the last. In this specimen a definite periostitis has occurred in the lower fragment, starting at the transfixion hole. This has caused a sheath of periosteal new bone to grow up round the fragments. But otherwise the latter are just as indolent in appearance as in the last experiment. Where the specimen has been cut down to show the structure, several of the pieces have fallen out.

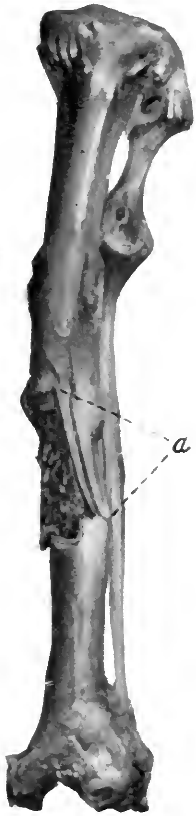


FIG. 157.—*Experiment* 15. Bone-dust grafting. After 6 weeks. *a*, Area reduced to powder.

The bone dust is replaced by connective tissue.

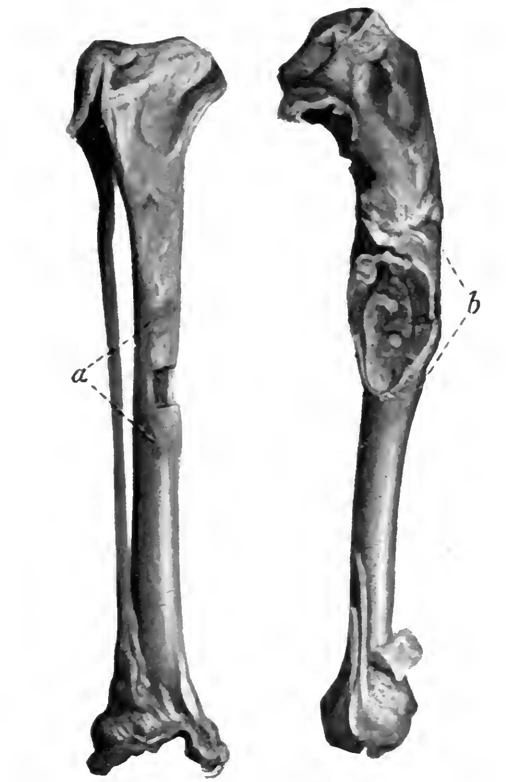


FIG. 158.—*Experiment* 16.

Right Tibia.—Half-thickness reduced to dust. *a*, Area of experiment. Re-formation of normal spongy bone.

Left Tibia.—Half-thickness fragmented. *b*, Area of experiment. Evidence of new bone.

Experiment 14 (*Fig.* 156) shows exactly the same result as *Experiment* 12. The fragments are loosely cemented together, one having fallen out when being cut, but there is no evidence of osteogenesis.

Experiment 15 (*Fig.* 157).—A piece of the whole thickness of the tibia was cut out, and reduced to powder by a small grinding machine made by a reamer working in a steel socket. The dust was replaced in its periosteal tube. After six weeks the bone dust had been completely absorbed, and replaced by blood-stained connective tissue. There is no evidence of new bone formation.

FIG. 159.—*Experiment* 16 (left tibia). Active osteogenesis is proceeding from one bone fragment.

FIG. 160.—*Experiment* 16 (right tibia). On the right is seen the compact bone of the shaft, from which is growing the new spongy bone. Only débris remains of the grafted bone dust.

Experiment 16 (*Fig.* 158).—Half the thickness was removed from both tibias for a distance of about an inch. On the left side the piece was broken up into little bits and replaced, on the right side it was reduced to powder and replaced. On the left side there was evidence of new bone formation round all the fragments, and this is borne out by microscopical examination (*Fig.* 159). On the right side, where dust was used, the tibia has re-formed to exactly its normal thickness. Microscopical examination shows that this is due to spongy callus growing from the bed of the cut shaft, and there is no trace of the dust except a little débris (*Fig.* 160).

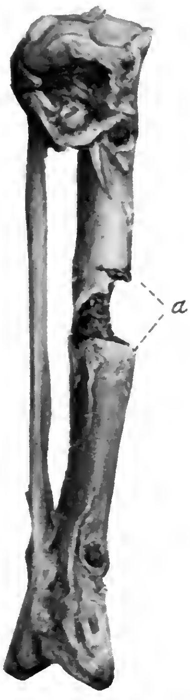


FIG. 161.

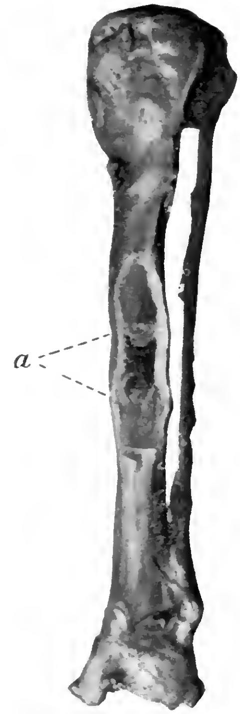


FIG. 162.

FIG. 161.—*Experiment* 17. Bone-dust graft. No new bone after 6 weeks.

FIG. 162.—*Experiment* 18. Bone-dust graft. *a*, Area of experiment. In this area there is no new bone, simply blood-stained connective tissue. A sheath of fibrocartilage has formed under the periosteum.

Experiment 17.—A piece of the tibia was removed and reduced to dust, and this was replaced in the gap. After six weeks there is nothing in the gap except blood-stained connective tissue (*Fig.* 161).

Experiment 18 (*Fig.* 162).—The same as the last. In this the gap is filled with connective tissue only, but the periosteum has formed a sheath of fibrocartilage. *Fig.* 163 shows the microscopical appearance. Callus is growing from the bone ends, and bits of the dust can be seen as débris.

This series of experiments demonstrates very conclusively that fragmentation of a living graft does nothing towards increasing its osteogenesis. In only one (*Experiment* 16) was there any evidence of an active osteogenesis occurring round the bits of bone. In this the whole thickness of the shaft had not been removed, but only half, and the pieces of bone were laid upon the raw bone and marrow surface. It is probable that, under the circumstances, the bits of bone quickly got a new blood-supply which promoted

FIG. 163.—*Experiment* 18. Spongy new bone in seen on the left, fibrocartilage on the right. (Just outside the microscopical field shown in the figure there is a fragment of bone dust, quite dead.)

their osteogenetic activity. But in all the other cases where bone chips were used to fill a gap, these acted in an extremely indolent fashion, and at the end of six weeks there was no bony union of the gap. Bone dust, too, is even more negative in its behaviour. Even when all precautions are taken, by using a coarse reamer, slowly revolving to prevent heating, the dust produced shows no osteogenetic properties. It is absorbed, and replaced by connective tissue.

D.—The Influence of Insecure Fixation.

When a bone-graft is used to fill a gap in a bone where there is no loss of continuity, it requires no suture fixation, because there is no tendency for it to be moved. But it is quite otherwise when a graft is used to bridge a gap in one

of the long bones, or to make good a defective repair of a fracture. Under these circumstances, even if external means of immobilization be most accurately applied, there is a tendency to movement between the graft and its bed which is very inimical to healing.

Experiment 19 (*Fig.* 164).—The femur of a cat was divided. From the superficial part of the shaft, above and below the fracture, a piece about half an inch long was cut out. Into the cavity a piece of the crest of the tibia was tied by two metal sutures. No other fixation. After six weeks there was

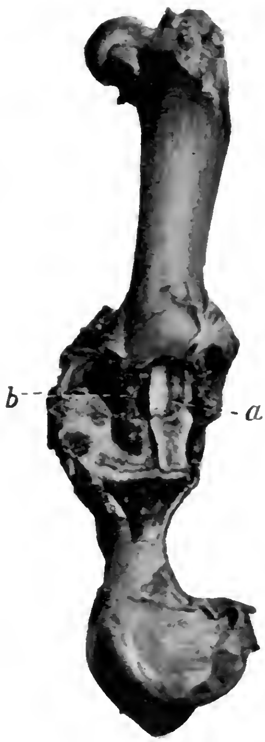


Fig. 164.

Fig. 165.

Fig. 164.—*Experiment* 19. Femur of cat, fractured, and repaired by an inlay graft of the tibia, secured by wires. After 6 weeks. *a*, Graft. *b*, Callus.
The graft has not taken at all, but there is great callus excess in the repair of the fracture.

Fig. 165.—*Experiment* 20. Fracture of tibia, with a graft from the same bone fixed by two wire sutures. After 6 weeks. *a*, Graft.
Faulty union, and no fixation of the graft.

massive callus union, but the graft was quite distinct, and had neither grown to its bed nor contributed in any way to repair, except that it had acted as a rather inefficient splint. The callus excess produced cannot be attributed to any specific stimulation of osteogenesis by the graft, because just the same growth occurs in any fracture of the lower end of the femur which is not completely immobilized.

Experiment 20 (*Fig.* 165).—The tibia of a cat was divided after a piece

one inch long had been cut from its anterior surface. This was re-applied, and fixed by two double sutures passed round the bone and the graft (*Fig.* 166). No supporting apparatus. It will be noticed that this method of fixation is very much less secure than that employed in *Experiments* 2, 3, 4. After six weeks the bone was badly united at a considerable angle. The graft was quite bare, and there was no union between it and the bed. The upper fragment had thrown out some epiosteal bone which had partly covered in the upper part of the graft.

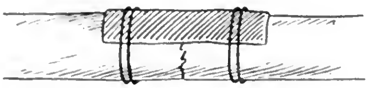


Fig. 166.—Diagram of graft fixed by two double wire sutures passed round graft and bone. Compare with *Fig.* 133.

Experiment 21 (*Fig.* 167).—A piece an inch long was removed from the front of the tibia. A gap a quarter of an inch long was made in the shaft, and the first piece was then re-applied, and fixed in place by catgut ligatures. The leg was fixed by a double-transfixion apparatus. After six weeks there was marked angulation. The upper end of the graft is united to the shaft by a firm fibrous band.

These experiments demonstrate the great importance of firm and lasting fixation of the graft to its bed. It is nothing more nor less than the necessity for firm fixation similarly observed in plant-grafting. It would hardly need demonstration or emphasis if it were not for the modern tendency to employ only absorbable ligatures. These afford no fixation in the real sense of the word after a few hours, when they become softened and yield before any strain. A comparison of the results of *Experiments* 2, 3, 4, 5, 6, and 7, in which efficient fixation by wire or pins was employed, with those where inefficient fixation by wire or suture by catgut was used, leaves no room for doubt, if such could ever seriously be entertained, that firm and lasting fixation of the graft to its bed is a factor of prime importance in all cases where continuity of the shaft of a long bone is destroyed.

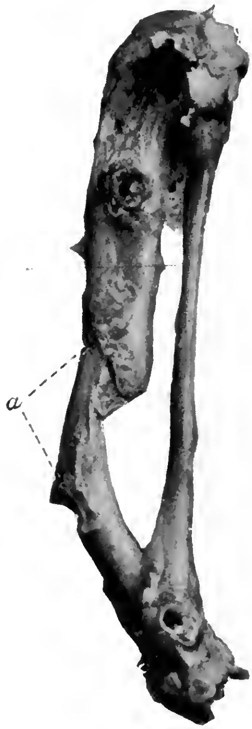


Fig. 167.—*Experiment* 21. Bone graft of the tibia used to bridge a gap. Fixation by catgut. After 6 weeks. *a*, Graft.

Faulty position, and no union between the graft and the lower fragment.

E.—The Reaction of Living Bone to Metallic Suture or Pins.

This subject is closely related to the last. In the first place a reference may be made to *Experiments* 2, 3, 4, 5, 6, and 7, in all of which ideal healing of a grafted bone occurred after the proper use of metal sutures or of perforating split-pins. In none of these was there any sign of excessive irritation, much less of suppuration or the formation of a sinus.

If a graft be tightly bolted to a piece of living bone, as in the accompanying diagram (*Fig.* 168), there will be observed two results :

1. At the points where the metal presses upon the bone, absorption will take place until tension is relieved, exactly as in the case of a suture tied tightly in the soft tissues. But this is a vital phenomenon. It involves vascularization and cellular proliferation of the bone, and these two processes are productive of new bone formation. In the case of a graft, where at first the circulation is absent and the cells of a low vitality, it will hardly occur at all, and therefore the loosening of the grip of a metal suture upon a bone-graft will not occur unless or until the graft begins to be vascularized and to grow.

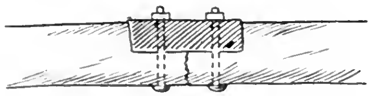


Fig. 168.—Diagram of graft fixed by bolts and nuts.

2. After a time the new bone grows round and encapsules the metal suture or pin in the manner demonstrated in *Experiments* 3 and 4. This stimulation of bone growth by metal foreign bodies is seen in a more pronounced degree in the following experiments.

Fig. 169.

Fig. 170.

Fig. 169.—*Experiment* 22. Femur of a cat after a simple fracture united by a long steel plate, showing the epiosteal bone beginning to ensheathe the metal. After 6 weeks.

Fig. 170.—*Experiment* 23. Femur of a cat after a simple fracture united by a steel plate and split pins. After 8 weeks. The plate is almost buried in epiosteal new bone.

Experiment 22 (*Fig.* 169).—A simple fracture of the femur in a cat, united by a long steel plate bearing four quadrant flanges which partly encircle the shaft, and through which are passed split-pins. After six weeks there is good massive union, though the plate has been bent a little. The plate and the ends of the pins are partly buried in epiosteal new bone. Healing was by primary union, and there was no suppuration.

Experiment 23 (*Fig.* 170).—This is similar to the last, except that the plate is a strong simple plate, and the pins perforate the whole thickness of the shaft. Killed after eight weeks. The plate and pins are almost buried in new epiosteal bone. Union was primary, and there was no suppuration.

These experiments, together with the previous ones, demonstrate that properly-applied metal sutures or pins serve to keep a graft accurately applied

to its bed whilst growth is occurring between the two, and that the living bone is not prevented from osteogenesis by their presence. Eventually they become encapsuled by a covering of new bone.

F.—Homogenous and Dead-bone Grafting.

Besides the living bone-graft taken from the same individual, i.e., the autogenous graft, there are two other possible sources of bone for filling osseous defects. These are the bones taken from other individuals of the same species—homogenous grafts—and dead bone. It seems to be so well established that bones of animals of another species act simply as dead bone, that it is not worth while to examine the possibilities of heterogenous grafts as distinct from the latter.

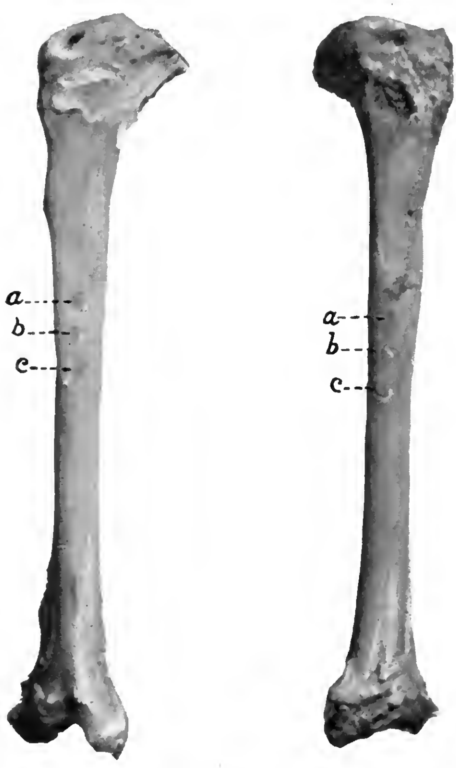


Fig. 171.—*Experiment* 24. Into both tibias of a cat three holes have been drilled. After 6 weeks. *a*, Hole filled with autogenous living bone. *b*, Homogenous living peg. *c*, Peg of boiled bone.
All have grown in place similarly.

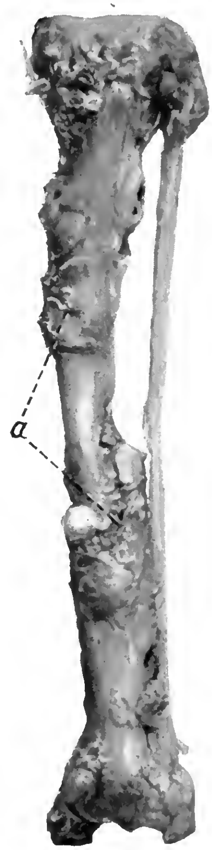


Fig. 172.—*Experiment* 25. A graft from the fresh femur of one cat fixed into a gap in another cat's tibia. After 6 weeks. *a*, Graft.

I know of only one observation contrary to this assertion, and that is Küttner's case of the implantation of the fibula of a Java ape to make good the absence of the fibula in a congenital defect. His skiagram shows the

survival of the bone; but it has not grown, and therefore there is nothing to prove that it retained its vitality, or acted differently from a dead bone.

Experiment 24.—**Autogenous, Homogenous, and Dead-bone Pegs.**—The anterior surface of a cat's tibia was drilled by an $\frac{1}{8}$-in. drill in three places (*Fig.* 171). Into the three holes were firmly driven round pegs, formed from: (1) The same cat's tibia; (2) The femur of another cat, recently killed; and (3) The same source as the last, the peg being boiled for half an hour. Both tibias were treated in this way, the one specimen being used for microscopical examination, the other being preserved whole.

After six weeks, all three pegs have become firmly incorporated into the shaft of the bone, and no difference can be detected between any of them.

FIG. 173.—*Experiment* 25. Rarefaction at the edge of a homogenous graft.

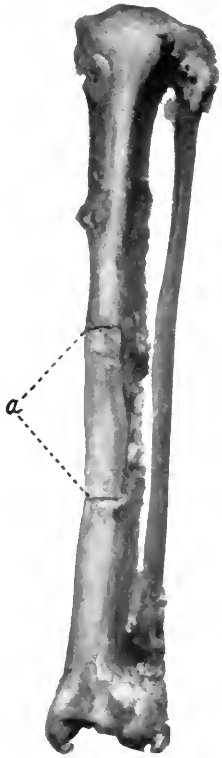
On sawing the specimen across, all the pegs are quite fixed, and show no tendency to fall out. Microscopically, there is very little difference to be noticed. The dense bone of the shaft round the pegs is rather more open in texture than normal, owing to new blood-spaces, and rather richer in cellular contents. The tissue of none of the pegs shows any surviving cells; it exhibits some erosion at the periphery, where it is being encroached upon by the living bone.

There is a practical importance in this observation, because it shows that when used as nails, dead-bone or ivory pegs act just as well as living ones. It is obvious that it is much more practical to have bone or ivory nails prepared of the right size and shape beforehand, than to prolong any bone-grafting operation in order roughly to ashion living pegs from the patient's bone.

Homogenous Bone-grafts.

Experiment 25 (*Figs.* 172, 173).—Into a gap in a cat's tibia was fixed a piece of the femur of another cat just killed. The fixation was similar to that employed in *Experiment* 5, by wire suture and a double-transfixion apparatus. The result, as judged by macroscopical and microscopical examination, was exactly the same as when an autogenous graft was employed.

Experiment 26 (*Fig.* 174).—This was exactly similar to the last. The result was even more favourable—not only had the graft grown to the bed at the end of six weeks, but the gap made in the shaft had become evenly filled with new bone.



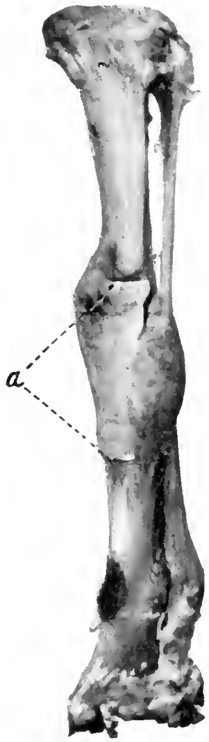


FIG. 174. FIG. 175.

FIG. 174.—*Experiment* 26. Homogenous graft from a cat's fresh femur into another cat's tibia. After 6 weeks. *a*, Graft.

FIG. 175.—*Experiment* 27. Homogenous graft from the tibia of one cat into that of another. After 6 weeks. *a*, Graft.

Experiment 27 (*Fig.* 175).—A piece of tibia of one cat was grafted into a gap in the tibia of another cat. It was fixed by wire sutures and transfixion. After six weeks the specimen shows firm bony union between the grafts and the bed, there being, however, a little displacement, with considerable callus excess. *Fig.* 176 shows the characteristic growth of new epiosteal, endosteal, and Haversian new bone in the graft.

The Comparison of Dead and Living Bone-grafts in the Repair of Defects in the Long Bones.

The observation recorded in *Experiment* 24 above, showing the similar behaviour of dead and living bone when used as pegs driven into compact bone, might lead to the assumption that a dead-bone graft would serve as well as a living one for the repair of a defect in the continuity of a long bone. In order to test this, a series of experiments was performed in which only half of the thickness of the shaft of the tibia was removed, the remainder not being fractured. Both tibias were operated upon in the same animal. Into the defect on one side was placed a living graft taken from the femur of another cat, just killed. On the other side was sutured a piece from the same bone (i.e., homogenous femur) which had been boiled for a quarter of an hour. No transfixion apparatus was used :—

Experiment 28 (*Fig.* 177).—Primary union occurred on both sides.

Left Tibia : Living Graft.—After eight weeks the bone is almost exactly re-formed. Along three sides of the graft and more than half of the fourth side there is bony union between it and its bed. Only on the smaller portion of one edge is there a distinct line between the two portions of bone.

Right Tibia : Dead Graft.—After eight weeks rather a remarkable condition exists. The line of the bone has been preserved. The graft lies quite smooth and bare in a cavity which is partly surrounded by callus overgrowth from the shaft. The shaft has undergone spontaneous fracture. That this

Fig 176.—*Experiment* 27. Red = graft : Blue = new bone tissue. *b*. Graft. *a*, Epiosteal. *c*, Endosteal. *d*, Haversian new bone formation.

is not a primary fracture, due to strain acting on the weakened bone, is shown by the fact of the bone as a whole having remained in good position whilst the callus involucrum was forming. One portion of the shaft to which the fragment was wired has undergone necrosis. The area in which the graft lay was covered by turbid fluid, and although this was encapsuled by the soft parts, and the skin was unbroken, it would probably in time have made its way to the surface and given rise to a sinus. In this specimen, therefore, not only has the graft not united, but a part of the shaft has necrosed, and actual solution of continuity of the bone has resulted.

Experiment 29 (*Fig.* 178).—The cat was killed after eight weeks.

Right Tibia : Living Graft.—Perfect bony union, the line between the graft and its bed being much obscured.

Left Tibia : Dead Graft.—Spontaneous fracture has occurred, with union in a position of much angulation, accompanied by great callus excess. The graft has, however, firmly united to the shaft of the bone above the fracture by dense bony union. Along one long side of the graft, between it and its bed, is a band of rather porous vascular bone (*Fig.* 178 x), evidently formed at the expense of the shaft, but nevertheless as firmly united to the graft as to the shaft. The huge mass of exuberant callus has been formed by the shaft below the fracture, and on one side it has almost covered in the grafted area.

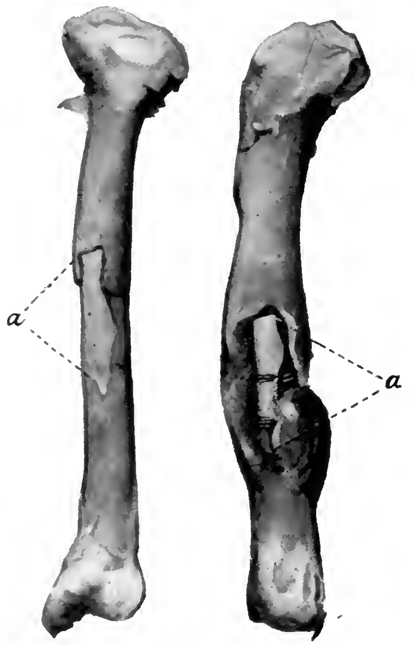


FIG. 177.—*Experiment* 28. Both tibias are from the same cat. The left-hand one has a living homogenous graft from a fresh cat's femur. The right-hand one has a boiled graft. *a*, Graft.

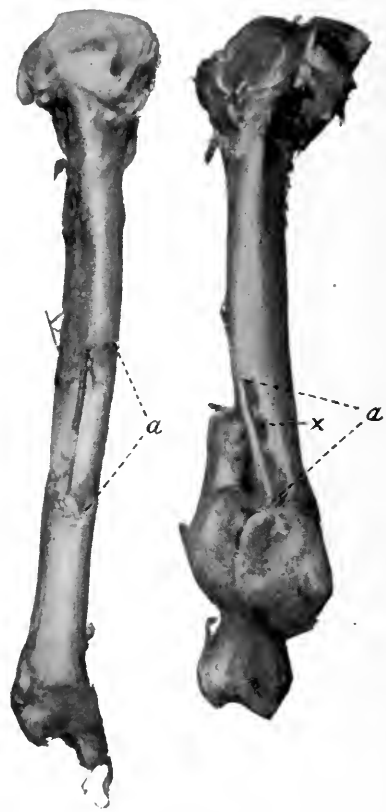


FIG. 178.—*Experiment* 29. Both tibias are from the same cat. On the left side is a living homogenous graft. On the right side is a boiled graft. *a*, Graft. x, Area of living bone which is penetrating *a*.

Experiment 30 (*Fig.* 179).—The animal was killed after eight weeks.

Right Tibia : Living Graft.—The graft has healed by firm osseous union. There is considerable overgrowth of epiosteal bone from the shaft, and this is beginning to grow up over the graft. There is slight angulation of the bone, which suggests that a partial fracture has occurred, accounting for the callus excess.

Left Tibia : Dead Graft.—There is firm union, with great callus excess, angulation of the bone suggesting a partial fracture of the shaft. Along a part of its periphery the graft is inseparable from its bed, but at other points it is quite distinct.

The general result of these three experiments clearly indicates the practical superiority of a living graft, even if taken from another animal of the same species, over a dead bone-graft. In all three the living grafts gave a very good result, whilst in all the dead graft gave a bad or indifferent one. The fact is remarkable that, in all cases, fracture of the shaft occurred when a defect in half its thickness had been repaired by a dead graft. This only occurred once with a living graft, and only in a slight degree.

Nevertheless, *Experiments* 29 and 30 certainly prove that a dead graft may actually become inseparably united to its bony bed, and therefore the employment of such a structure cannot be regarded as useless if other material is unavailable.

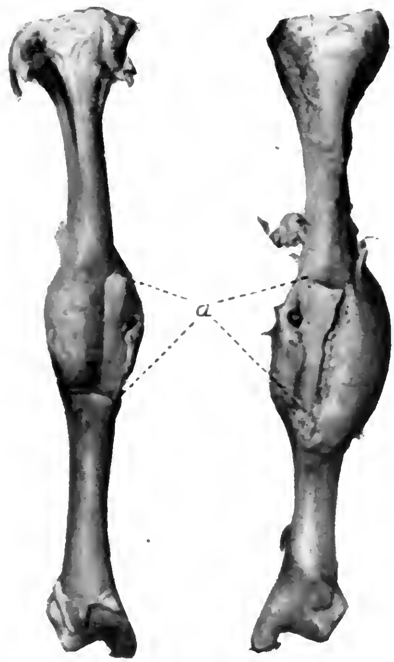


FIG. 179.—*Experiment* 30. Both tibias are from the same cat. On the left side is a homogenous living bone-graft. On the right side is a boiled graft. After 8 weeks. *a*, Graft.

SUMMARY OF EXPERIMENTAL RESULTS.

1. The most ideal graft is a piece of living bone used in its entire thickness.
2. Any kind of bone-graft gives better results when used whole than when broken up into small fragments.
3. Fragments of living bone, unless closely in contact with vascular tissue, act as indolent and passive structures, and display no osteogenesis.
4. Dust formed from living bone does not maintain its vitality.
5. Cortical grafts are far better than intramedullary.
6. An intramedullary graft, if small and loose, takes no part in repair, neither does it act as a splint. If it fits the marrow cavities of the fragments tightly, it hinders osteogenesis and is frequently subject to fracture.
7. The success of a living graft depends very largely upon : (*a*) The extent of its contact with living bone ; (*b*) The accuracy of its apposition ; (*c*) The firmness of its fixation.
8. Firmness of fixation is of paramount importance in the repair of defects in long bones by grafting.
9. A graft of dead bone (boiled), properly fixed by metal sutures, will give a better result than a living autogenous graft fixed by catgut alone.
10. Metal sutures and pins are useful in the fixation of many grafts. When properly applied they secure the necessary fixation, and there is no evidence that they hinder osteogenesis.

11. For use as pegs or nails there is no advantage in using living over dead bone.

12. Homogenous grafts, under favourable circumstances, act just as well as autogenous.

13. Dead bone-grafts are certainly inferior to living when used to fill defects in the long bones, but under favourable circumstances they become strongly incorporated into the living skeleton.

14. Provided that secure fixation of the graft to its bed is not disturbed, mobility of the limb favours osteogenesis, whilst immobilization hinders it. (Compare *Experiments* 3, 28, 29, 30, where no fixation apparatus was used, with *Experiments* 5, 25, 26, where the limb was held by the double-transfixion splint.)

III. CLINICAL METHODS: GENERAL PRINCIPLES.

Aseptic Technique.—Unfortunately there has arisen an idea that bone surgery requires a special form of aseptic ritual. The reasons for this are various. In the days before aseptic surgery, septic infection was so frequent and so severe as a result of operations upon bones, that no direct attack upon them was justified except as a matter of grave urgency. The contrast between the course of an open and that of a closed fracture in pre-antiseptic days was held to be evidence enough of the dangers of open exposure of bone tissue. When Lane first essayed to operate upon closed fractures, he had to face this prejudice, and in order to do so he established a very rigorous technique. The main features of this are that no finger touches either the wound or anything put into the wound; hæmostasis is by forcipressure, and no ligatures are applied. This technique has been continued by many to the present day, and it is accountable for the fact that operative measures are limited to simple and superficial manipulations, e.g., the screwing of a plate on to the surface of a bone. Since Lane first began operating on closed fractures, aseptic technique has so greatly improved that his precautions are quite unnecessary. Rubber gloves are perfectly able to render finger-touch sterile, and in order to avoid the danger of tearing, cotton gloves may be worn over the rubber. Good bone surgery, and especially bone grafting, requires accurate fitting and fixing, and for these manipulations the fingers are necessary. The 'don't-touch-the-wound' technique, I venture to think, is not justified by its results: when by its use plates are screwed to bones, in many cases a subsequent sinus is formed, necessitating a further operation for the removal of plate and screws. The inefficient mechanical fixation imposed by the long instruments and absence of finger contact allows movement between the bones and the plate, thus causing an outpouring of fluid, which leaks through the old scar and then sets up secondary infection. Sound mechanical fixation, accurate fitting, and tight suturing are much more sure means of preventing infection than merely keeping the fingers out of the wound.

Exclusion of the skin surface from contact with the fingers and the instruments is very important. I have found that the simplest way of attaining this is as follows: The skin is prepared beforehand by shaving and by iodine. After the anæsthetic, iodine is again freely swabbed over the limb, and allowed to dry. Then a length of the tubular woven material known as stockingette,

which has been sterilized, is passed over the limb, fixed above by a bandage, and below it is tied together. The necessary incisions are then made through this material and the skin. The edges of the stockingette are fixed by Michel's Clips to the cut skin edges, and this is not disturbed until the very last stage in the operation. This method is not only very effective in excluding the skin from the wound, but it is very convenient when more than one incision has to be made, e.g., when both radius and ulna have to be exposed. The avoidance of forceps attaching the material to the skin is an advantage, because the operative field is not encumbered by these, nor is there any risk of their slipping off. The soft parts should be held aside by a suitable self-retaining retractor, so that they are bruised as little as possible by handling.

Latent Sepsis.—It is a matter of clinical and experimental evidence that the occurrence of a slight degree of sepsis does not prevent bone repair, though it generally hinders and delays it. It might therefore be thought that in dealing with the late results of an open septic fracture, it is not necessary to wait for the absolute subsidence of sepsis before attempting a bone-graft. But this is a very serious mistake. After a septic fracture, active inflammation may subside until only a sinus remains; or this may heal up and yet, in the scar tissue, real infective material of a very active sort remain latent, and any wide opening up of the tissues will cause this latent sepsis to spring into a most malign activity. In any case where a sinus remains, or any open wound, it is utterly unjustifiable to attempt a bone-grafting operation. The right thing to do is to extirpate the sinus, and then, when healing has occurred, to wait for several months, treating the limb by massage. If no septic relapse occurs under this treatment, then the further operation may be undertaken. Methods of treating the sinus by injections of bismuth or iodoform, which are quite good for ordinary purposes, seem to me rather dangerous here. They may subdue the sepsis enough to allow of healing, but there is always a great risk that germs are merely encapsuled and will be released into activity when the parts are opened up. It is much better to wait a long time, and to do several operations for the excision of sinuses and the removal of loose bits of bone, than to light up a severe septic conflagration by a premature bone-grafting, as this not only endangers the life of the limb, but certainly will cause loss of more bone from necrosis.

The Treatment of Scar-tissue.—After most septic gunshot fractures there remains much scar-tissue. This may be quite sound if it is left alone, but it is thoroughly bad material on which to rely for plastic surgery. The behaviour of cutaneous scars is most striking. A recent skin scar appears simply to melt away when it is part of a new operation wound or when it lies in a flap. Probably the same thing applies to deep scar-tissue. It can neither nourish itself nor afford nourishment to a graft when its connections are disturbed. Therefore it must be laid down as a primary rule for bone-grafting, that cutaneous scar-tissue must be replaced by healthy skin before the operation, and deep scars must be excised during the operation. This really constitutes one of the main difficulties of the problem, and it must be fairly met and not evaded. By cutaneous scar-tissue I mean any considerable loss of substance which has been covered over by a mere epithelial cicatrix. If this is small in

extent, it should be excised, the skin freed from underlying bone, fatty connective tissue interposed, and the skin sewn together so as to heal by first intention. If the scar is larger, a flap must be made, either from the limb itself or from some other part of the body, and time given for this stage in plastic repair to be complete before the bone is touched.

I would repeat that before any bone-graft is undertaken for the results of a septic fracture, three things are necessary, or perhaps I should say four. These are:—

1. Sinuses must be healed soundly.
2. Cutaneous epithelial scars must be replaced by thick healthy skin.
3. The skin must not be adherent to the bone: all retracted, adherent scars must be obliterated by fat.
4. Sufficient time must be given for these measures to produce consolidated repair; probably four to six months.

The observation of these precautions will not only secure smooth healing of the bone-graft, it has another advantage. Whilst waiting for superficial plastic repair, the bone often mends itself by a growth from the divided ends and by osteogenesis from fragments left in the gap.

The Source of the Graft.—In the great majority of cases, defects in continuity of the bones should be filled by autogenous grafts. In order to supply these, there are three readily available sources, viz., the crest and anterior portions of the tibia, the upper part of the fibula, and the ribs.

The Use of the Tibia.—Of late years the crest and inner surface of the tibia has quite rightly been the most favoured source of autogenous grafts. From it may be fashioned a piece of bone up to ten inches in length, and having a square section half an inch wide in each direction. The crest of the tibia is the strongest piece of dense bone of suitable length in the body. On two surfaces periosteum can be preserved, and endosteum on the other two. Its tissue is firm, and allows of firm holding by pegs, wire sutures, or bolts. Against these advantages must be placed two drawbacks. The very dense bone of the tibial crest is poorly supplied with both blood-vessels and osteoblasts, and therefore it cannot furnish much osteogenetic activity. Secondly, the removal of the strongest part of the tibia has often led to fracture of the remaining part of the shaft. Neither of these disadvantages is of determining importance. The graft is so strong and can be fixed so securely, that its slow growth in thickness is not of any moment. The liability of the rest of the bone to fracture has only to be recognized to be guarded against, by providing a light plaster case for the affected leg if the patient is to walk upon it within six weeks of the operation.

When great strength is not required in a graft, as in the filling up of gaps in skulls, it is better to avoid the crest of the tibia, and to take a flat piece from the inner surface.

The Use of the Fibula.—A long length of graft can be obtained from the fibula much more readily than from the tibia, and with much less traumatism. Such a graft seems to be capable of more rapid increase in thickness than is the case with a bit of tibia. Its use is therefore indicated when a long piece of either the femur or humerus has been removed, as for example in resection for an endogenous tumour. It is also very useful in the replacement of a large

gap in either radius or ulna—that is to say, when the defect is too great to be filled by a piece taken from half the thickness of the injured bone itself. Another possible indication for the use of the fibula is as a substitute for the head of the femur. In this case the head of the fibula would be used, with three inches of the shaft ; the latter would be driven through the trochanteric region of the femur at the proper angle.

The Use of the Ribs.—The rib has often been used for grafting. The tenth rib can readily be spared, and it is easily removed and as easily cut. Its natural bend has suggested its use for the substitution of curved bones, e.g., the jaw. But it is very doubtful whether it is really suitable for grafting purposes when the attainment desired is that of a strong permanent bone. In the first place, in many instances when it has been used (e.g., McWilliams), it has quickly become absorbed. Secondly, its spongy structure makes it difficult to fix firmly by wire or pegs. We cannot ignore the factor of individuality in bones. A rib is not designed to bear a heavy strain, and when transplanted, it never seems to grow into a dense hard bone like one of the long bones of the limbs.

The Composition of the Graft.—Whatever view may be taken of the exact function of the periosteum and medulla, there can be no doubt that the preservation of both these structures is a matter of importance in taking a living graft. Although new bone is probably the product of osteoblasts of the graft, nevertheless it is on the surfaces of the dense bone, i.e. from epiosteum and endosteum, that this new bone is laid down. The periosteum and marrow protect these surfaces, and act as vascularizing tissue to them.

The preservation of the periosteum on a graft is a simple matter. But there are two points of detail which are important : (1) All muscle and tendon insertion should be dissected off the graft, as these greatly delay the establishment of new vascular supply ; (2) The periosteum should be cut longitudinally by several incisions in order to release the underlying osteoblasts. The marrow is of less importance than the periosteum, and it is not worth while to sacrifice the strength of a tubular graft by splitting this down the middle. But access to the marrow cavity can be readily secured at points other than the two ends of the bone, by making several drill-holes through the compact tissue into the medullary cavity.

Homogenous and Dead Bone-Grafts.—The indication for the employment of other than autogenous grafts is perfectly well defined. It is when the defect to be made good includes all or part of the articular end of the long bones where such articular surface depends for its function upon its exact shape and its cartilaginous covering. The best examples of the kind are the head of the femur and the lower end of the humerus. For such defects no autogenous graft can supply an efficient substitute, and there have been a sufficient number of successes in the use of both of homogenous and dead grafts to justify their employment.

The homogenous graft can seldom be obtained from an amputated limb, but must be taken from a corpse. The subject from which it is removed should have been free from any infective disease, the best being one who has been killed by accident. The possibility of accidental post-mortem contamination should be guarded against by taking a culture from the graft, and not using

the latter for a period of twenty-four hours, when the incubated culture will have had time to reveal the presence of pyogenic organisms. During this period the graft should be kept in a sterile receptacle in the ice chest.

In the preparation of a dead graft, the easiest method is to take the bones from a corpse, and to subject the same to prolonged boiling after maceration. The other alternative, which has been adopted by König with good results, is to have a part fashioned out of ivory. The relative advantages of a sterile human bone and of an ivory prothesis cannot be stated positively as the result of experimental evidence. Ivory in large bulk (e.g., enough to make the upper end of a femur) is expensive and difficult to obtain. On the other hand, its great density makes it less readily absorbed than would be the case with more open bone. But we do not know whether this density may not have the definite disadvantage of hindering the ingrowth of living tissue necessary for the functional incorporation of the graft. The extraordinarily rapid and firm attachment of dead to living bone, which has been demonstrated in the above experiments, would seem to me to indicate that if living bone cannot be obtained, then sterilized human bone is the best substance for the graft. The object for which ivory is of undoubted value is for the fashioning of pegs, nails, bolts, or screws.

Previous Preparation of the Graft.—One fact about the behaviour of living grafts is very prominent. The dense bone, which is essential for strength, acts with extreme indolence, and no active osteogenesis such as can be demontrated by the *x* rays occurs from it for many months. Whether this is due to the death of the osteoblasts, or to its want of vascularization, is uncertain; but it would seem to be a reasonable thing to subject the portion of bone destined for a graft to previous treatment, in order to increase both its vascularity and cellular content, and to render easier the communication between its interior and the tissues of its future bed.

Lately, I have been carrying this out as follows: At a period of about four weeks before the injured limb will be ready for the graft, the tibia from which the graft is to be taken is exposed by a flap incision. The periosteum is cut by longitudinal incisions for every quarter of an inch of its exposed surface, and then the cuts are deepened by the saw. In these cuts a small drill ($\frac{1}{16}$-in.) is used to bore holes right into the marrow cavity at distances of about three-quarters of an inch. In this way the area of the future graft, six inches long, will be scored by five or six incisions and perforated by about thirty holes. At the end of four to six weeks this area of bone is much thicker than before, and it is also red and vascular instead of being very white and bloodless. Enough time has not yet elapsed to show whether this preparation of the graft leads to increased rapidity and degree of osteogenesis, but the facts already observed encourage the hope that this is the case.

Cutting the Graft.—It will be sufficient to describe the taking of a tibial graft. The area from which the graft is to be taken should be exposed by a long flap incision. The length of the graft should allow of a generous overlapping of its ends beyond the gap to be filled, to provide for secure fixation and a large area of apposition with the living bone at both ends. At least an inch of overlapping should be provided for at each end. The area of the

graft should be marked out by a scalpel-cut through the periosteum, but this periosteal incision should be about a quarter of an inch wide of the line of the saw-cuts. This allows an edge of periosteum to project all round the graft for the purpose of suturing the latter to the tissues of the bed. If the graft is required merely to fill a defect in the skull, or in a small bone, and not to bear much strain, it is sufficient to take a strip from the inner surface of the tibia, not including the crest. But if it is intended to supply a long gap in the humerus, femur, or tibia, then the strong tibial crest must be included, and the graft will have a square or a triangular section.

The actual cutting of the graft should be made by a circular saw actuated by an electric motor. The motor saw outfit now in most general use is that of Albee. It consists of a very small motor (about $\frac{1}{25}$ horse-power) in a case held in the hand, with the saw directly attached by a rigid shaft. The disadvantages of this are that the weight of the motor has to be held in the hand, and that the available power is so small that it is difficult to deal with a thick tibial crest. Preferable to it, I think, is a more powerful motor on a stand, connected with the saw by a flexible cable. The motor I use is of $\frac{1}{10}$ horse power, and an arrangement is provided by which either a direct drive can be employed at high speed (1500 revolutions a minute), or else a geared drive can be used, which reduces the speed to 300 revolutions per minute, with a corresponding increase in power. This slow speed is of advantage not only in being more manageable and more powerful, but in producing less heat in cutting the bone.

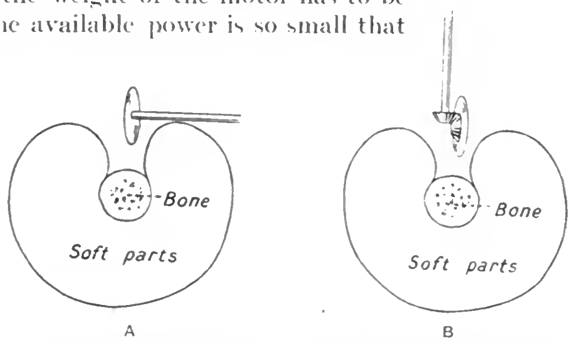


FIG. 180.—A. Diagram of ordinary circular saw, cutting at right angles to its shaft. B. Author's saw, cutting parallel to its shaft.

The ordinary circular saw cuts in a plane at right angles to the shaft which propels it, and this often makes it difficult to deal with a bone surrounded by soft parts, because the shaft comes in contact with the latter. This difficulty is overcome by using a saw which I have designed, in which the blade works parallel with its actuating shaft (*Fig.* 180).

The use of a twin saw makes it possible to cut a graft with exactly parallel sides, and this can then be fitted into a slot cut by the same saw (*Fig.* 181). It is, however, rather doubtful whether there is much advantage in this, and there are some disadvantages. The saws have a certain

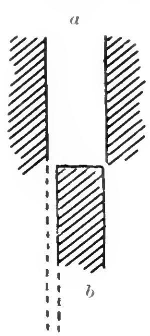


FIG. 181.—Diagram showing loose fit of the graft in its bed when both graft and slot are cut by the same twin saw. The space between the dotted lines indicates the thickness of the saw-cut. *a*, Slot. *b*, Graft.

thickness, and if the same twin saw be used to cut both the graft and its bed, then the graft will be loose by just the thickness of the saw-cuts. Most commonly the tibial graft is taken for its strength, and then it must be cut by two distinct cuts at right angles to one another, one on the inner and the other on the outer surface of the bone (*Fig.* 182).

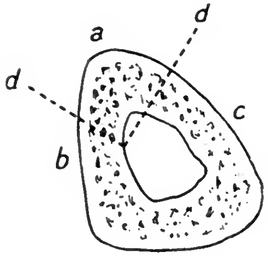


FIG. 182.—Diagram of transverse section of tibia, showing saw-cuts used for taking a strong graft. *a*, Crest. *b*, Outer surface. *c*, Inner surface. *d*, Dotted lines showing direction of saw-cuts.

The upper and lower ends of the graft should be marked at each angle by a drilled hole, and these are then joined by a saw-cut (*Fig.* 183). The longitudinal saw-cuts need not be so deep as to free the graft completely. In fact, it is better to complete this by the use of a chisel. The latter tool subjects the bone to less traumatism than the saw, and it does not choke up its canals with bone dust.

For cutting a graft from small bones, e.g. the ulna or radius, and for the shaping of the bone ends when these can be lifted clear of the soft parts, a metal fret-saw is much more convenient than a motor saw.

The Preparation of the Bone to be Repaired.—The matter of bone-grafting is comparatively easy when it can be done with tissues which are normal, and into a bone which is not displaced. Such conditions, for example, as are presented when the upper end of the humerus has been removed for an endosteal sarcoma. It is most difficult, on the other hand, when done to repair defects left by injury accompanied by sepsis.

The matters of latent sepsis and untrustworthy scars have already been referred to. But other difficulties still remain to be overcome. These are due to the presence of deep dense scar-tissue, and to the gross deformity of the bone which has resulted from loss of substance and the contraction of soft parts. Such difficulties would be great in proportion to the absence of support by a parallel bone—e.g., in the femur, the period during which sepsis has been present, and the absence of proper orthopædic treatment.

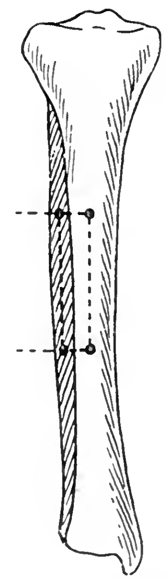


FIG. 183. — Diagram showing the four drill-holes and four saw-cuts used in cutting a strong tibial graft.

In the matter of one of the forearm bones, when its fellow remains sound, there is very little distortion. Sometimes, too, the fibula remains intact and serves to splint the tibia. In these circumstances there is no necessity for special correction of bone deformity before laying the graft. If, however, there is much deformity, and if it is intended to correct this, and not merely to splice a crooked bone, then this correction must be very carefully undertaken as a preliminary to, or as the first stages of, the operation. Suppose, for example, the femur has been broken and four inches of its substance lost, the ends of the bone are close together,

buried in deep fibrous tissue, and there may be both lateral and axial displacement. These conditions are quite common, and impose so many difficulties, that hitherto the possibility of bone-grafting has hardly been considered, and the unfortunate patient is simply left with his deformed leg four inches short and with a false joint.

There are many less extreme cases, where the bone to be mended is grossly deformed, and in which the correction of the deformity must precede any attempt at grafting. The necessity for this correction is threefold: First, it will ensure a straight limb of full length; secondly, it will make the act of grafting much simpler; and thirdly, it will impose much less strain and tension on the connection between the graft and its bed.

Consider, for example, the case of a broken tibia in which there is a gap originally of four inches, reduced perhaps to less than an inch, with much angulation, when treatment is begun. If a grafting operation is undertaken forthwith, there will be a most tedious, difficult, and laborious manipulation before the bones can be straightened and extended to a proper length. In fact, in many cases these difficulties will be found to be insuperable. But if proper extension be applied to the limb, then, after an interval of about seven days, the scar tissue will be stretched and the alinement corrected. In bad cases the lower end of the bone should be transfixed by a steel pin, or grasped by a screw clamp, and then pulled upon in the correct line by a suitable weight of ten to fifteen pounds for the period named. If further correction is necessary at the time of the grafting operation, a second transfixion pin can then be placed through the upper fragment, and by means of a screw extension apparatus the two parts of the bone can be forcibly separated and held in position during the grafting. This apparatus can be left in place for some days. After the operation it will serve to steady the mended bone and to relieve the bone sutures of all tension.

In other cases where the bone is not so large, or the difficulty of the reduction not so great, one or other of the simpler extension instruments may be used.

The necessity for corrective extension of a broken bone prior to grafting is not merely to make easier the grafting operation. It is to overcome the tension which would otherwise be thrown on the graft and its fixing sutures, which tension will greatly endanger its fixation.

Methods of Fitting the Graft to its Bed.—The accurate fitting and fixing of the graft to its bed is a very important part of the operation. The evidence of the experimental work which I have detailed has impressed me very strongly with this point. The greater accuracy and firmness that is used in fitting the graft, the smoother will be the healing and the quicker will be functional recovery. Vital union will depend upon the surface contact between the two parts of bone, and upon fixation being both firm and lasting. In special cases, of course, special fitting methods may be used, but for the repairing of a gap in the length of a tubular bone, the methods of fixing may be described under six different heads.

1. *The Inlay Graft.*—In this, a narrow strip of bone is cut, either from one of the fragments of the damaged bone or from the inner surface of the tibia. It is laid into a corresponding groove cut in the bed. This method is

only suitable for one of a pair of parallel bones, where there is neither much gap nor much displacement. It is mechanically weak, and leaves a large gap to be filled by new bone.

2. *The Intramedullary Graft.*—This method is much the easiest, as the graft will only require to be roughly shaped as a peg at each end and fitted into the marrow cavity of each fragment, requiring no other fixation. The evidence, however, both clinical and experimental, shows that this method does not always succeed. It is somewhat weak and insecure, and osteogenesis is very slow. Union of the graft with its bed is not so firm or so rapid as in the cortical methods, and there is a real danger of the graft becoming broken.

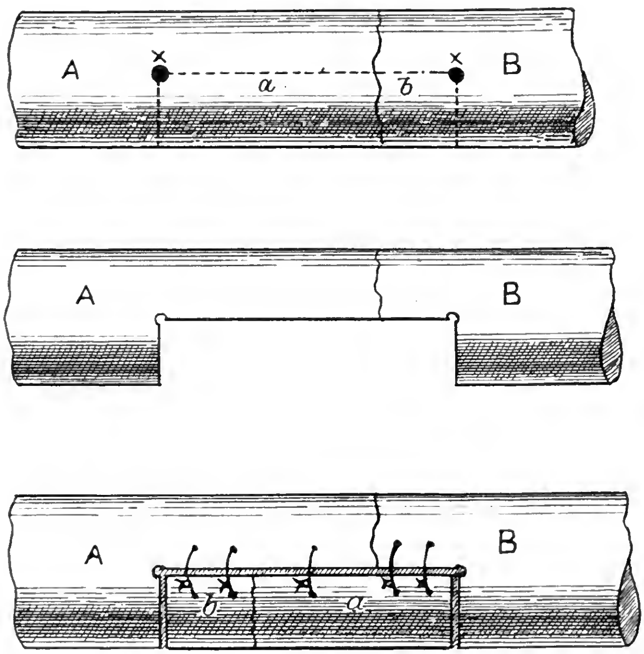


FIG. 184.—Half-cylinder graft, fixed by wire sutures: bone-grafting by the cutting of unequal pieces from the fragments of a fracture, and then reversing them. In the upper figure the fragments A and B are bored at points x x, and cuts made so as to take a piece *a* from A more than twice as long as the piece *b* from B. In the middle figure these pieces are removed. In the lower figure the piece *a* has been placed in the angle of B, and the piece *b* in the angle of A, and there sutured by wire sutures.

3. *The Half-Cylinder Graft.*—In this the bed is cut through for half its thickness and a piece removed about an inch long. The graft is cut of about half the thickness of the bone to be mended, and its two ends are fitted into the steps cut in the fragments. This method is one which combines easy performance with considerable mechanical efficiency. It was the method which gave the best results in the above experiments. It fills up the gap by a piece of bone half the thickness of the shaft, and only leaves a half-thickness to be restored by new bone. It permits of very firm fixation by means either of wire sutures or of bolts (*Figs.* 184, 185).

4. *The Cylinder Graft.*—This and the following methods are only possible when the graft can be cut from a bone of the same thickness as that to be repaired. Practically, they will be limited in autogenous grafting to the repair of the forearm bones by a piece of fibula; but they can be used for the larger bones if a homogenous or dead graft is employed. The cylinder graft is illustrated in *Experiment* 1. A section of the bone is cut as the graft, just long enough to fill the gap, and the tension of the bone and that of the surrounding soft parts is enough to keep it in place. It is only suitable for the repairing a long gap in one of the forearm bones when the companion bone is quite sound.

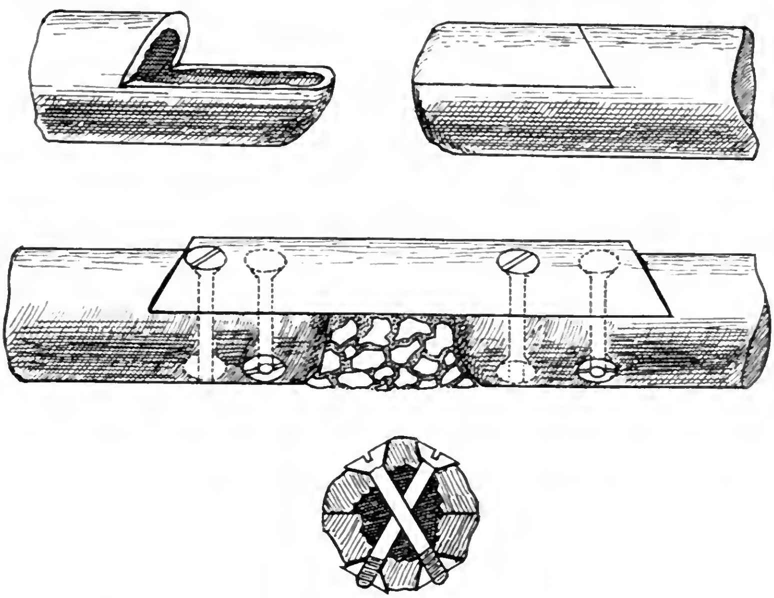


FIG. 185.—Half-cylinder graft fixed by bolts. In the upper figure the bone ends are shown cut for the reception of the graft. In the middle figure the graft is seen bolted in place, the pieces of bone cut from the original fragments being divided up and placed in the gap. The lower figure shows the junction of the graft and the bone in transverse section.

5. *The Mortised Cylinder.*—This is the same as the last, except that the graft is cut about two inches longer than the gap it is to fill, and each end is cut away in half its thickness for an inch. A corresponding step is cut in each fragment, and the graft fitted in place.

6. *The Pegged Cylinder.*—This is similar to the cylinder graft, but there is provided in its axis an ivory or dead bone peg which fits into the marrow cavities of the two fragments.

The advantage of the cylinder grafts is that they entirely fill the gap, and no cavity is left for restitution by new bone.

The Fixation of the Graft.—Every type of graft used to fill a gap in a long bone must be securely fixed. Some form of suture will be necessary in all except the medullary or cylinder grafts. This suture ought to be of some

metallic material, or of ivory. My reasons for this have been stated in the experimental section.

It seems to me quite unreasonable to deal with rigid skeletal structures by materials such as catgut or kangaroo tendon, that is, unless the graft is in such a place that there will be no tendency to its displacement, e.g., in a gap in the skull; here no suture at all will be necessary. Either use no suture to fix a bone, or else use a metal or ivory fixation material.

The Use of Wire.—The best material is soft iron wire, which I now employ without any plating. It is much cheaper and stronger than silver and less irritating to the tissues than copper or bronze.

The best way to use it is to place it as a mattress suture through two holes in both the graft and its bed. This, however, is often impracticable when dealing with small bones, and then one or two turns of wire round the whole shaft will act very well. A groove may be made by a file or saw, and

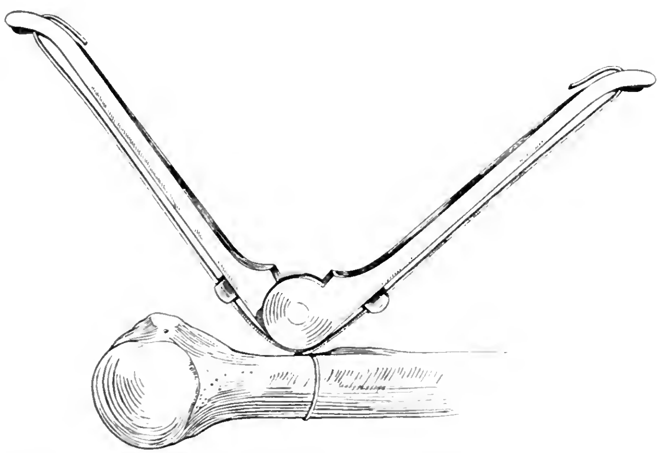


FIG. 186.—Author's wire-tightening forceps. The wire is passed round the bone, its ends are crossed, then laid in slots in the sides of the forceps, and turned round the V-shaped ends of the handles. When these are closed together the wire is tightened, and can then be twisted.

in this the suture lies snugly. It is very important that wire sutures should be so tied that no slack is left which may allow play between the bones. If only thin wire is used (No. 20 Standard Wire Gauge), long pieces should be employed, passed twice round the bone, and by means of the long ends, grasped by forceps, pulled quite tight before being twisted and cut short. If stout wire (No. 14 S.W.G.) is used for a big bone, it ought to be drawn tight before twisting, for which purpose I have devised a special instrument (*Fig.* 186).

Metal Pins.—Ordinary cotter-pins are very useful for small bones. These are $\frac{1}{8}$ inch in thickness, and split, so that when they have been passed through the bone and the graft, a small washer is slipped over the end, and the halves of the pin are separated, cut short, and pressed back. This device has been illustrated in the above experiments.

Metal Bolts.—Bolts which excellently serve all purposes for bone grafting are made of iron $\frac{1}{8}$ inch thick and in length from $1\frac{1}{2}$ to 4 inches; the head of the bolt is cut for a screw-driver, whilst the nut may be either hexagonal or milled. The graft is held to the bed by a catch forceps. Both are drilled through in two or three places, the direction of the drill-holes being in different radii of the cylinder. The bolts are placed before removing the forceps. The nuts are screwed home tightly after countersinking the holes, and the projecting part of the bolt is cut off by shears.

Ivory Pegs or Bolts.—Instead of using metal pins or bolts, these may be made of ivory. The advantage of this is that the substance actually becomes incorporated in the bone, and I think that in future, as we become accustomed to the use of this material, it will be more and more used. I have now four types of ivory pegs. First, the intramedullary peg, which is really a dead bone graft. Secondly, a square or round nail, which should be left rough and not polished. Thirdly, screws cut from ivory after the pattern of metal screws; to use these, the hole made in the bone and the graft must be prepared by having a female thread cut in by a special tap. Fourthly, ivory bolts; these are thicker than the metal bolts, namely, $\frac{5}{32}$ inch, and the nuts are also wider.

Treatment of Periosteum and Fragments.—In all manipulations of the injured bone the periosteum should be freely raised from those parts of the bone which have to be exposed. This is for two reasons: first, because the mere raising of the periosteum stimulates the underlying bone to osteogenesis; and secondly, because the great value of the periosteum is due to its blood-supply. If the membrane is left with its connections to the soft parts undisturbed, then its power as a vascularizing membrane will be undiminished; whereas, if the soft parts are first raised from the periosteum, this act will temporarily rob the bone of part of its blood-supply.

In all ways of fitting a graft into a bone defect, except that of intramedullary pegging, there are fragments cut from the bone ends in shaping these for the reception of the graft. These should not be discarded, unless the graft completely fills the gap. They should be placed in the gap, closely packed, in the manner shown in *Fig.* 185. It is true that these fragments will not play any very active part in osteogenesis; but they will in time become incorporated with the rest of the bone, and they serve to make the time of final consolidation shorter.

Suture of the Soft Parts.—After the graft is fixed in place, the periosteum of bed and graft should be sewn together, if possible by catgut. Then the muscles, and finally the deep fascia, are carefully sutured over the bone. The more deeply the mended bone is buried in soft tissues, the less danger is there of secondary infection taking place from the skin surfaces. Also, careful deep suture will obliterate any dead spaces, and prevent the formation of blood-collections, which hinder the bone from becoming attached to the soft parts and vascularized by them. Drainage by strands of silkworm-gut for forty-eight hours is a wise precaution whenever there has been much oozing.

After-treatment.—All surgeons are agreed that it is necessary that a bone which has been grafted should be immobilized for several weeks or months after the operation. If the graft has not been firmly fixed to its bed

by metal sutures, then, in order to carry out this immobilization, it will be necessary to encase the limb in plaster of Paris, including the joints above and below. In fact, some surgeons advise that the whole limb should always be encased in plaster from the girdle to the digits. But there are great drawbacks to this procedure. The wound cannot be inspected, or a drain removed, without cutting off the plaster. Whatever functional disability has existed before the operation will be greatly increased by the rigid case. Muscles will atrophy, and the joints become very stiff. Further, it is a matter of common observation that absolute immobilization of a whole limb leads to atrophy of the bones themselves, and this at the very time when the one thing needed is new bone growth. I have shown, too, by experimental evidence, that provided the graft is securely fixed to its bed, new bone growth takes place better when no immobilization is employed. I would therefore urge very strongly that the main factor in immobilization should be the actual fixation of the graft to its bed. If necessary, this may be supplemented by the use of long steel plates, such as those shown in *Experiments* 22 and 23, these being bolted to the whole thickness of the bone, and not merely attached by superficial screws. But however it is done, the fixation of the graft should be internal and not external.

A light supporting splint is used for a few weeks, and when the wound is healed, the limb is taken down every day, and subjected to light massage with movements of the joints. In this way the nutrition of the muscles and the flexibility of tendons and joints are preserved, whilst the formation of new bone is encouraged.*

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* This Paper, together with a list of the author's clinical cases, formed the Jacksonian Prize Essay for 1917. Owing to exigencies of space the latter portion is postponed to a future issue. The expense of the experimental portion of this work was defrayed by a grant from the British Medical Association to whom the author wishes to express his thanks.

A CASE OF OSTEO-ANEURYSM.

DIFFUSE TRAUMATIC ANEURYSM IN THE SURGICAL NECK OF THE HUMERUS.

By R. LAWFORD KNAGGS, Leeds.

Osteo-aneurysm is an old term that is used to describe pulsating tumours of bone. It may be presumed that the word was originally employed because the pulsation in such cases was expansile and was sometimes associated with a bruit. That the idea of aneurysm in some form or other was believed to be a possibility is shown by the report on Bickersteth's case in the *Pathological Society's Transactions*, xix, 348. A careful perusal of the case, however, leaves the impression that it was one of new growth, notwithstanding the following report by two well-known surgeons of a past generation: "We entirely agree with the author in his description of this specimen, and look upon it as an admirable example of aneurysm commencing in the lower extremity of the tibia, expanding the bone, and extending backwards into the muscles and soft parts behind the tibia." This was all. Only the macroscopic appearances were described, and no histological examination seems to have been made.

At the present time pulsating tumours of bone are very generally thought to be true tumours, and undoubtedly those usually met with are growths of varying degrees of malignancy, and also of very different macroscopic and microscopic features. Probably there is no real belief nowadays in an aneurysm of bone which has the same pathology as spontaneous or traumatic aneurysm elsewhere. The best accounts of osteo-aneurysm are to be found in the older text-books: in the more modern works on surgery there is a tendency for the subject to be treated very shortly or to be omitted altogether. But in none have I been able to find a case referred to in which the description made it clear that a blood tumour communicating with the interior of an artery, and having a definite circumscribed sac, was the cause of the symptoms.

I hope, however, to show that such cases may occur, and as they are most likely to be traumatic aneurysms, and not unlikely to result from gunshot injuries to the bones, the recognition of that fact at the present time is not without its value.

Pte. E. E. W. was wounded in the left shoulder on Sept. 15, 1915. He was treated in a general hospital in France for thirteen days, was then sent home, and was admitted into the 2nd Northern General Hospital on Oct. 2.

A bullet had passed through the surgical neck of the left humerus. The wound of entry was behind the shoulder over the posterior fibres of the deltoid, and the bullet had passed out through the centre of the upper part of the biceps. Both wounds were healthy, and apparently superficial, when he was

admitted. On the night of Oct. 21 the man had a bad night owing to a great deal of pain in the shoulder, and next morning pulsation was first detected about an inch above the exit wound. Careful examination showed that the upper part of the shaft was considerably enlarged, and that this enlargement was the subject of expansile pulsation, which was at once perceptible when the bone was held between the fingers of both hands. The main artery could be felt to be quite normal as it coursed over the internal aspect of the swelling. No bruit could be made out, and there was no thrill.

A skiagram that had been taken on Oct. 16 (*Fig.* 187) showed a large irregular aperture in the surgical neck, with comminution of the internal surface, the fragments being displaced as if they had been forced outwards by the

FIG. 187.—Skiagram taken on Oct. 16.

explosive effect of the bullet. On Oct. 31 an enlarged gland was noticed in the supraclavicular fossa. The general swelling of the shoulder that had followed the wound had now completely subsided, and the increasing expansion of the bone showed as a definite rounded tumour about the size of a cricket ball, altering the normal contour of the limb.

Another skiagram, taken on Oct. 30 (*Fig.* 188), confirmed the increased expansion of the bone and the further enlargement of the space in the interior.

The case, being one of great interest, was seen by most of my colleagues, and there was a general agreement in a diagnosis of rapidly-growing endosteal sarcoma. When the serious nature of the condition was explained to the patient, he at once agreed to lose his arm.

On Nov. 1 he was anæsthetized, and an incision was made through the deltoid into the tumour. A mass of black clot was evacuated; but nothing was seen that looked like tumour tissue. The evacuation of the clot was followed by very free arterial bleeding, and the cavity was at once firmly packed whilst the position was reconsidered. It was felt that even yet there was no certainty that we had not a growth to deal with, for it is well known that in some cases only careful examination of the cyst wall may reveal that a blood cyst of bone is really due to sarcoma. Moreover, if the condition were not due to growth, an attempt to save the arm would be attended by such danger that amputation later—when the patient's condition might have been seriously impaired by secondary hæmorrhage and suppuration—would probably be

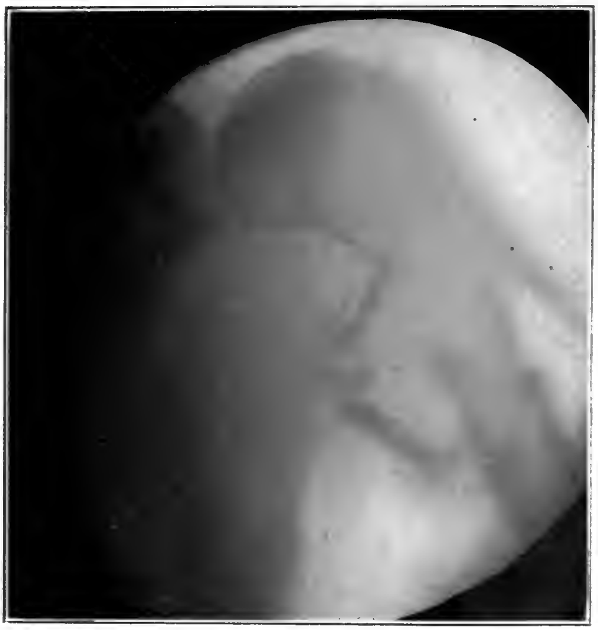

FIG. 183.—Skiagram taken on Oct. 30.

imperative. So it was decided to proceed, and the interscapulothoracic amputation was performed by Littlewood's method, i.e., from behind. The operation was well borne; a rapid recovery followed, and after a period at a convalescent home the patient was signed up as fit for the adaptation of an artificial limb on Feb. 21, 1917.

The tumour was examined immediately after the operation. The contents were black clot, and as this was being turned out, towards the end, a piece of dark red membrane, equal in extent to about one square inch, was seen amongst it. This membrane was evidently a portion of the sac of a traumatic aneurysm. To anyone who had seen many cases of traumatic aneurysm—as I suppose most surgeons to the large military hospitals have—the

character of this membrane was conclusive. From the moment of its appearance no doubt whatever was felt as to the real nature of the case. Therefore at a later date a more careful examination of the interior of the cyst was made, and a portion of the anterior wall removed in order to expose the cavity more

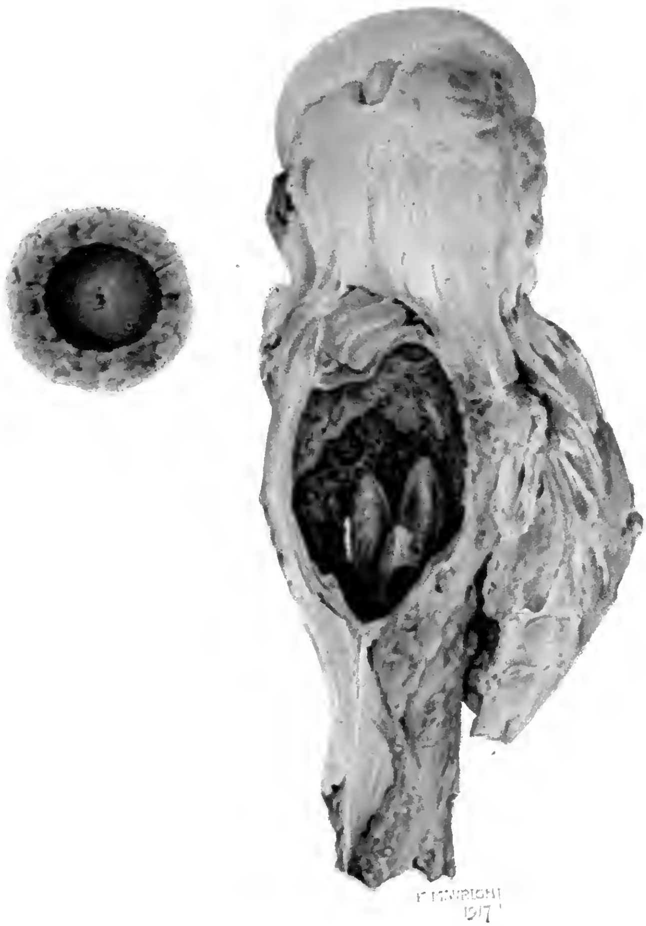

Fig. 189.—Drawing of the specimen.—The position of the remaining portion of the original aneurysmal sac is indicated at the extreme upper limit of the bone cyst. Miss Wright has represented it at a lower level than its true one, for it was concealed behind the overhanging edge of the cyst wall and could only be seen by looking upwards through the opening. The small sketch is an enlarged representation of the cup-shaped cavity. The little dark spot in the right lower quadrant is the aperture which had the appearance of an opening into a small vessel. The central discoloration is probably due to traces of adherent clot over a roughness caused by underlying inequalities of bone.

thoroughly. This was rewarded by the discovery of a portion of the original aneurysmal sac in the highest part of the cavity (*Fig.* 189). It was situated beneath the anterior wall of the cyst in the upper part of the surgical neck. It formed a hollow in the cancellous tissue big enough to receive, as in a cup, a very

small Barcelona nut. Its lining membrane was smooth and shiny, of the same dark-red colour as the piece of membrane described above, and it was adherent to the bone to which it was closely applied. On one side of this cup, by the help of a magnifying glass, a small aperture could be seen which was suggestive of an opening in a small vessel. The smooth glistening character of this membranous lining was in sharp contrast with the rough, irregular, and dark-coloured remains of old clot, which covered the rest of the interior of the cavity in the bone, and through which the bone splinters projected.

It only remains now for the pathological examination to be recorded. Portions from the wall of the cyst were examined by Capt. M. J. Stewart, the clinical pathologist at the General Infirmary and of the East Leeds War Hospital, and by Dr. O. C. Gruner. Both agreed that there was no evidence of sarcoma to be found, and I now give the report which Dr. Gruner has kindly drawn up. The gland unfortunately was lost.

> *Report on Wall of Bone Cyst.*—Two portions of the wall were taken at different places. The thinner portion is composed of laminated blood-clot in which there is some admixture with fibroblasts. The thicker portion shows attenuated bone trabeculæ rather widely separated from one another by a tissue which has a homogeneous matrix and is occupied by granulation tissue. Lymphocytes and small plasma cells occur between the capillary loops. There is no evidence of sarcoma. The wall of the cyst appears therefore to be constituted by organizing ossifying granulation tissue.

There can be no doubt that this was an instance of a traumatic aneurysm occurring in the interior of the humerus, and that it probably ruptured and became diffused on the night of Oct. 21, when the patient suffered for the first time since his admission with severe pain in the shoulder.

In conclusion, and with much pleasure, I would like to acknowledge the assistance received in this and many other anxious cases from my Commanding Officer and old colleague, Lieutenant-Colonel Littlewood.

GUNSHOT WOUNDS OF THE KIDNEY AND URETER AS SEEN AT THE BASE.*

By Colonel ANDREW FULLERTON, C.M.G., A.M.S.,
Consulting Surgeon, British Expeditionary Force.

In this article the term gunshot wounds will be used in the widest sense to include all injuries produced by the missiles employed in modern warfare. The remarks which follow are based on the examination of 42 cases seen at the base. Many of these have been imperfectly studied, but this is unavoidable under the conditions obtaining, even so far back from the firing line. Under stress of work it is impossible to carry out elaborate investigations, and the urgent necessity for evacuation of patients, to make room for others arriving from the front, has prevented the final results in many cases being ascertained. Enough material has, however, been available to indicate the lines on which further investigation may be carried out. A short summary of cases will be given at the end, so that reference may be made to any case mentioned in the text.

CLASSIFICATION.

Wounds of the Kidney.—These may be classified into: (1) *Those involving the Hilum*; and (2) *Those Involving the Parenchyma of the Organ.*

1. Wounds Involving the Hilum.—These may be divided into (*a*) Those involving the blood-vessels supplying the organ; and (*b*) Those involving the pelvis.

a. Those Involving the Vessels.—If the main renal artery is divided, the patient may die of hæmorrhage before he reaches the clearing station or the base. If one of its branches is divided, the hæmorrhage may not be sufficient to cause death. In that case the area of the kidney supplied by this branch will undergo necrosis. It is important to remember, in dealing with injuries to the blood-vessels of the kidney, that the arteries are terminal or end arteries, though the veins anastomose. Division or blocking, therefore, of an artery going to the organ will be followed by death of the area of distribution of that artery. The importance of this fact was brought to my mind some years ago. I had occasion to explore a kidney in a healthy male subject, and an aberrant artery to the upper pole had to be divided before the organ could be brought into view. Some weeks later I had again to operate on this kidney, and I now found that a large part of the upper pole was of a dull yellowish-white colour, and this area was sharply marked off from the remaining healthy portion. In the same way, an injury in the parenchyma to a branch of the renal artery will be followed by necrosis of the part supplied by it.

* A lecture delivered before the Boulogne Medical Society, on June 22, 1917.

b. Those Involving the Pelvis of the Kidney.—Wounds involving the pelvis of the kidney alone are not very frequent, as other complications are likely to be present. These wounds allow of the discharge of urine into the perirenal tissues and through the wound in the parietes. If the peritoneal cavity has been opened by the missile, urine may leak into it and produce peritonitis.

2. Wounds of the Parenchyma of the Kidney.—These may be so severe and extensive as to reduce the organ to pulp, and all grades between this condition and a small perforating wound, produced by a bullet or a small fragment of shell, are seen. Most of the more extensive wounds are dealt with at the casualty clearing stations, but those of less severity are frequently treated at the base. The character of the wound will depend on the

Fig. 190.—Recent shell wound of lower pole of kidney. The patient died from other wounds a few hours after being hit. The cavity of the wound is filled with blood-clot and disintegrated kidney substance. Lacerated masses of renal tissue fungate through the torn capsule. Columns of blood infiltrate the cracks, fissures, and loose areolar spaces leading towards the uninjured parts of the organ. The pelvis is filled with blood-clot.

nature and size of the missile, and, no doubt, on the range of fire. Many of the wounds of the parenchyma doubtless involve the infundibula and calices, but escape of urine is not likely to take place unless the wound is large and has extended into the pelvis of the kidney itself. If urine escapes from the external wound, the inference is that the pelvis or ureter has been injured. The effects of the missile on the structure of the kidney will be more fully dealt with later.

Wounds of the Ureter.—Wounds of the ureter have not been very frequent at the base. In most cases one would expect these to be but a small part of more severe injuries involving intestine, blood-vessels, etc. The feature of these wounds is the escape of urine externally, and they will be dealt with under the heading of Urinary Fistula.

EFFECTS OF THE MISSILE ON THE KIDNEY.

The effects produced by a missile on the kidney will depend on (1) the direct damage caused by the missile; (2) the damage due to interference with the vascular supply; (3) the damage resulting from pressure of hæmorrhage; and (4) the results of sepsis.

Macroscopic Appearances.—If a fresh wound of the kidney be examined (*Fig.* 190), the following appearances will be found. The cavity or track of the wound is filled with blood-clot and disintegrated kidney substance. Lacerated masses of renal tissue fungate through the torn capsule. Columns of blood infiltrate the cracks, fissures, and loose areolar spaces leading towards the uninjured parts of the organ. The pelvis contains blood-clot. Occasionally, one finds small subcapsular hæmorrhages, or a few points of ecchymosis in parts remote from the injury.

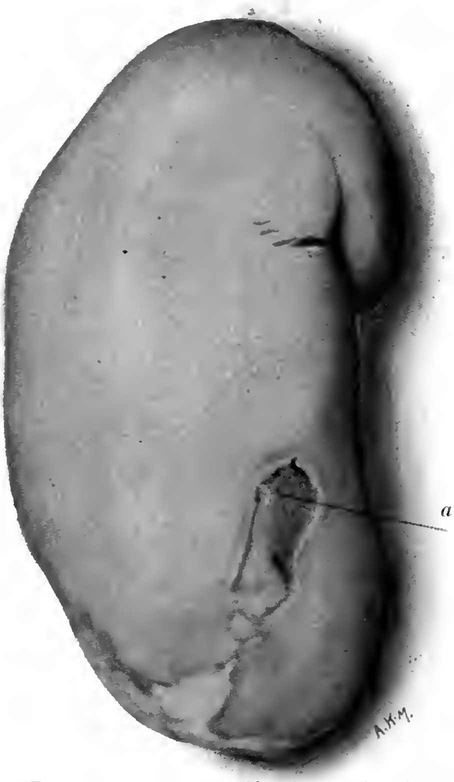

Fig. 191.—*Case* 30. Showing perforating wound of kidney, surrounded by an area of necrosis, and an area of necrosis in cortex. Twelve days after injury. *a*. Perforating wound.

If a wound of the kidney is examined some days after the injury, certain vascular effects will have become manifest:—

1. The missile in its passage may have damaged one or more of the arteries lying in the intervals between the pyramids. In this case the territory supplied by these vessels will have undergone necrosis, and will stand out from the rest of the kidney as yellowish-white areas. This is well shown in *Figs.* 191, 192.

2. Thrombosis extending from the neighbourhood of the wound may have interfered with the vascular supply of the contiguous portion of the organ. This will be apparent as a ring of yellowish-white colour surrounding the margins of the wound, contrasting strongly with the neighbouring healthy portion (*Figs.* 191, 193, and 195).

3. The pressure of the extravasated blood may have produced nutritional changes in the adjoining kidney-substance. In this case there is a tendency to recovery as the blood-clot becomes absorbed.

4. Portions of the fungating kidney-substance in the wound itself will have become necrotic (*Fig.* 193). If sepsis is present, inflammatory changes

in the kidney and its pelvis will be added. The fungating masses will be covered with greyish sloughs (*Fig.* 193), during the separation of which secondary hæmorrhage may take place.

Types of Injury.—The types of injury to the kidney with which we are familiar as the result of our present experience may be classified as follows :—

1. *Injury to a branch of the renal artery without direct involvement of the kidney itself.*—We were fortunate in obtaining a specimen in which a large branch had been injured without immediately fatal results. In this case (*Case* 31), a large branch of the renal artery going to the lower pole was divided. The patient died from a concomitant injury to his spine, ten days after the wound was inflicted. The whole of the area supplied by the injured branch underwent necrosis. A beautiful drawing of the kidney was made by Sergeant Maxwell (*Fig.* 194). It will be seen that the greater part of the lower pole has died. Surrounding the necrotic area is a narrow red zone indicating the line of demarcation between the dead and living tissue. The patient had suffered from moderate hæmaturia.

Fig. 192.—Kidney in section from same case as *Fig.* 191. Note the perforating wound filled with blood-clot and disintegrated kidney substance, and the area of necrosis due to involvement of a branch of the artery. Twelve days after injury. *a*. Perforating wound.

The kidney differs from the lung and liver in not possessing a collateral circulation. Hence, the rapid absorption and disappearance of infarcts, which is a feature in injuries to the blood-vessels of the lung and liver, is not likely to occur in the kidney. The final result in the above case, presuming that the patient had recovered and the wound had remained aseptic, would probably have been a large scar replacing the necrosed area.

2. *Contusion of the kidney, produced by the passage of a missile in the vicinity without actual contact with the organ.*—In *Case* 37, a large fragment of shell entered the back to the left of the spine, just below the outer end of the last rib. *X* rays showed the fragment lying in the spinal canal between the 2nd and 3rd lumbar vertebræ. Laminectomy was performed,

and the fragment was removed from the site indicated in the skiagram. The track of the missile, which had crossed the region of the kidney, was investigated, but there was no evidence of direct injury to that organ. The patient had suffered from hæmaturia from the day of his injury. In *Case* 7, a piece of shell had entered in the right posterior axillary line, and had passed across the middle line, finally lodging in the left half of the theca between the 11th and 12th dorsal vertebræ. Post mortem, a hæmatoma was found at the upper pole of the right kidney, between the capsule and the kidney substance, and there was ecchymosis of the upper pole below the hæmatoma. The piece of shell did not strike the kidney itself. Colonel Wallace, in the Lettsomian Lectures for 1917, draws attention to a case in which many cracks were produced in the capsule by shell fragments which did not touch the organ itself.

3. *Perforating wounds of the kidney.*—These are produced by bullets or fragments of metal. Both entrance and exit wounds may be small, or the exit wound may be pyramidal in shape and larger than the entrance wound. *Figs.* 191 and 192 illustrate this type of wound.

4. *Tangential wounds.*—A good example of these is seen in *Fig.* 195, taken from *Case* 14. A furrow has been ploughed obliquely in the posterior surface of the kidney by a small piece of shell which is seen resting near the upper pole. Surrounding the track is the area of necrosis to which attention has already been drawn.

5. *Wounds destroying one or other pole of a large area of the kidney.*—In *Case* 42, as may be seen in *Fig.* 193, a large bite has been taken from the middle of the outer border of the organ. There was a large suppurating hæmatoma around the kidney. The patient died thirteen days after being wounded, and the vascular effects of his injury are apparent in the necrotic area surrounding the wound, and in the fungating kidney-substance in the wound itself.

In *Case* 41, in which the kidney was removed for secondary hæmorrhage fourteen days after injury, the following appearances were seen. There was a large mass of fungating tissue on the convexity of the lower pole. The central part of this pole was occupied by irregular lacerated and necrotic patches. Surrounding these parts was a peripheral zone of deep purple subcapsular hæmorrhage. The pelvis of the kidney contained blood-clot. Round the stitch-holes, made at a previous operation at a clearing station, were small irregular patches of necrosis. On section, necrosis seemed to be limited to the cortex. In some places hæmorrhage extended along the pyramids towards the papillæ, but the structure of the pyramids, though they were deeply engorged, was apparently intact. The remainder of the kidney was pale, but otherwise apparently normal.

6. *Extensive destruction of the kidney.*—Cases with extensive destruction are frequently seen at the clearing stations, where the damaged organ is usually removed. In some the kidney is broken into many fragments; or less extensive injuries, such as large fissures or irregular star-shaped wounds, may be present. In *Case* 26, the organ was found completely divided into two portions. An almost similar condition was found in *Case* 2.

Microscopical Appearances. — In the foregoing paragraphs the gross effects of the missile have been described. It remains now to enquire into the effects on the apparently uninjured and, to the naked eye, normal parts of the organ remote from the injury. The effects of injury to vessels upon the area supplied by them has already been mentioned. The effects of the missile on the kidney may be ascertained by microscopical examination, and, to some extent, by clinical investigations on the function of the damaged organ. I propose to deal briefly with the microscopical appearances of sections taken from various parts of injured kidneys, and to mention a case in which both microscopical examination and clinical investigation of the kidney function were carried out. Later, I shall append what clinical evidence I have been able to obtain as to the function of the damaged organ as ascertained by cystoscopy.

Fig. 193.—*Case* 42. Large lacerated wound of kidney. Note surrounding area of necrosis, and masses of fungating kidney substance becoming necrotic. Thirteen days after injury.

Sir Anthony Bowlby,[1] in the Bradshaw Lecture for 1915, expresses the opinion that, even in apparently trivial wounds, the damage to the kidney may be more extensive than the naked-eye appearances would lead one to suspect. In support of this he quotes a case in which microscopical examination of sections, made by Captains Stokes and McNee from parts of the kidney distant from the obvious injury, showed extensive disorganization.

Captain E. F. Bashford,[2] referring to the case in question, cannot agree with the interpretation of the appearances seen in the figure accompanying the description, and details the microscopical anatomy of two other cases of recent injury, and supplies descriptive figures. From a study of the sections in these cases, he comes to the conclusion that the injury to the kidney in both was of a strictly local character.

Microscopical examination seems, in three at least of the four cases about to be mentioned, to confirm Captain Bashford's views as to the limited nature of the injury produced by certain wounds of the kidney. In the fourth case, it is difficult to say how far local and general sepsis was responsible for the changes present in the sections from the remoter parts of the organ.

In *Case* 30 (*see Figs.* 191 and 192), a piece of shell had passed through the lower pole of the kidney. The track of the missile was dark-red in colour, and was surrounded by a narrow zone of yellowish-white colour in the fresh specimen. In addition, there was a pyramidal zone of necrosis of the extent shown in the drawing. Portions of the kidney were sent to Dr. J. A. Murray,

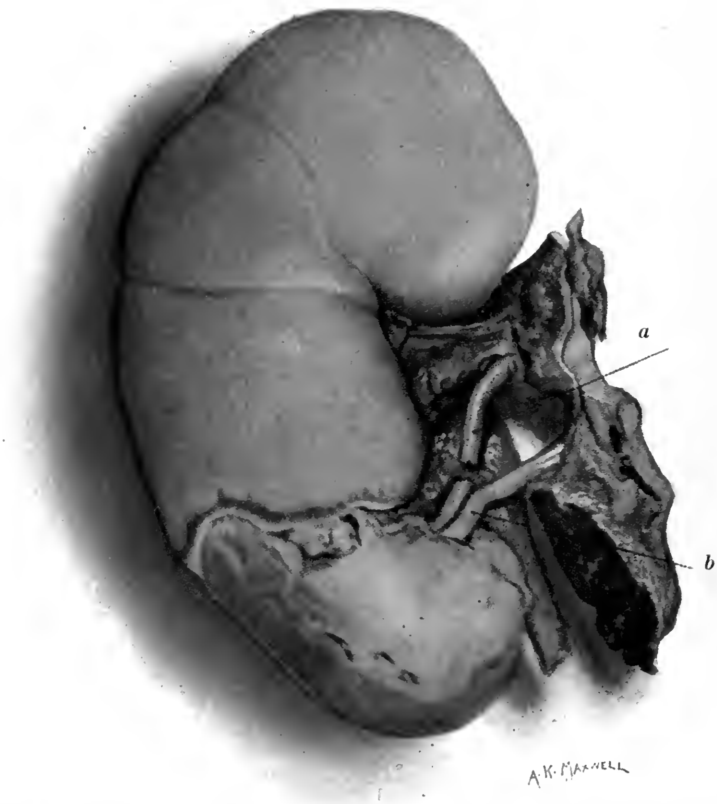

FIG. 194.—*Case* 31. Injury to a large branch of the renal artery, followed by necrosis of the lower pole of the kidney. A portion of the fleshy infiltrated perirenal tissue is shown. Fifteen days after injury. *a*. Branch of renal artery ; *b*. Branch of renal vein.

of the Imperial Cancer Research Fund, who kindly furnished microscopical sections, which were examined by him and by Captain Herbert Henry. Dr. Murray reports :—

In this case there is a good deal of hæmorrhage around the injury, and widespread fatty degeneration of the kidney tubules. The interstitial connective tissue is increased throughout, but this is so uniform that it may have been an antecedent condition.

Captain Henry confirms this opinion, and also reports that the kidney sections at a distance from the injury show a normal structure. Cystoscopic

examination had previously revealed blood but no pus in the specimen taken by ureteral catheter from the affected side, and normal urine of good specific gravity from the uninjured side.

In *Case* 32, the kidney showed near the centre a small perforating wound produced by a fragment of shell, almost exactly similar to the wound in the last case. Sections were made by Dr. J. A. Murray, who reports as follows :—

In this case the processes of repair are more advanced [than in *Case* 30]. There is considerable formation of granulation tissue under the organizing blood-clot. The epithelium of the tubules shows very little fatty change. In the region of the wound only is there much alteration, and some of those tubules contain masses of fibrin filaments, indicating the previous existence of hæmorrhage. I should imagine that the second case is of longer standing than the first, but do not care to express a definite opinion without the clinical notes.

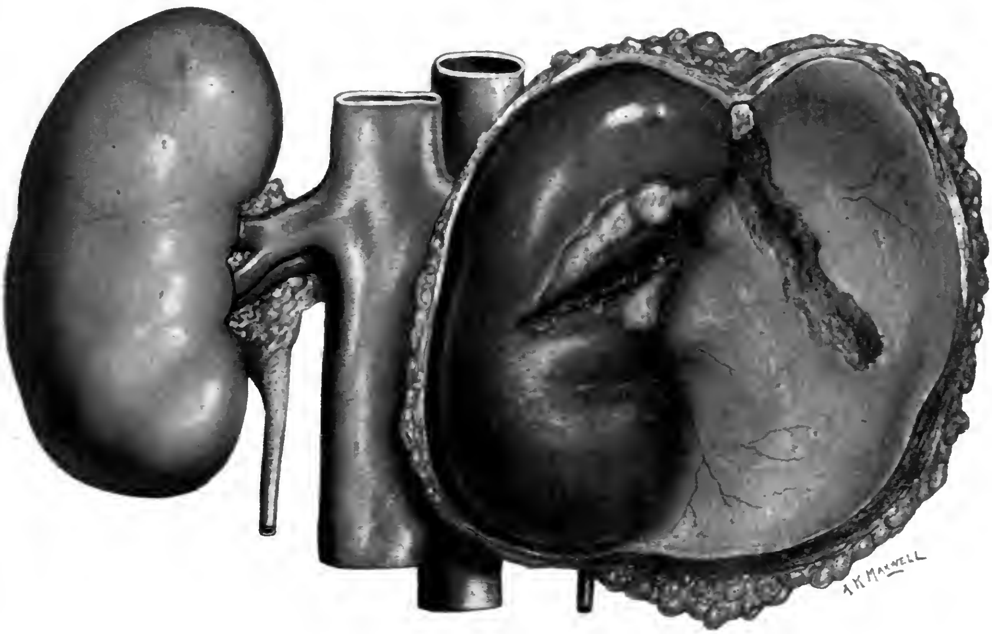

FIG. 195.—*Case* 14. Tangential wound of kidney. The piece of shell is seen at the upper pole. Patches of necrosis bordering on track. Some infiltration of perirenal tissues. Twenty-four days after injury. The perirenal tissue has been reflected from the posterior surface of the kidney.

This opinion is correct. In the previous case (*Case* 30) the kidney was removed twelve days after injury, while in *Case* 32 nephrectomy was performed one month after injury. The microscopical sections of the latter case were also examined by Captain Henry, who agrees with the interpretation of Dr. Murray.

In *Case* 24, I have received microscopical sections from Major McEwen which he has kindly prepared for me from the kidney, removed by him for

secondary hæmorrhage on the seventh day after the injury. The injury to the kidney was more severe than those we have been considering, but the case may with advantage be mentioned here. A large ragged wound, produced by a shell fragment, was found extending from the cortex into the pelvis of the kidney. Portions were taken for microscopical examination (*a*) from the wounded area and parts of the organ immediately adjacent; (*b*) from an area of necrosis in the cortex; and (*c*) from a part of the kidney distant from the wound. Captain Henry kindly examined the sections, and reported as follows:—

a. Purulent infiltration in parts, with large giant phagocytic cells containing destroyed blood-pigment; skeleton only of kidney tissue left in one set of slides, the capillaries and intertubular spaces being filled with active polymorph cells; attempts at regeneration in certain tubules, and marked fibroplastic reactive changes. Summary: The area of damaged kidney tissue shows: (1) Destruction of parenchyma in various stages, with purulent infiltration; and (2) Reactive changes, consisting chiefly of fibroplastic healing, and, to a much slighter extent, attempted regeneration.

b. Infarcted kidney, avascular and with no reactive changes, badly staining.

c. Apparently normal kidney.

In *Case* 14, already referred to, in which the missile had grooved the posterior surface of the kidney, microscopical sections were made by Captain Hopwood from various parts of the injured kidney and also from the uninjured one. Captain Hopwood's report is as follows:—

In the track of the missile.—There is hyperæmia, hæmorrhage, necrosis of kidney cells in varying stages, and round-celled infiltration.

In the yellowish-white patches bordering on the wound.—There is hyperæmia, hæmorrhage, and total necrosis, including tubules and glomeruli. Even in the glomeruli, all nuclei have disappeared. In the other parts, round-celled infiltration and definite casts, as the result of hæmorrhage, are seen.

In the area of the kidney distant from the track.—Parenchymatous degeneration and necrotic parts are found in the tubules rather than in the glomeruli. Tubular epithelium degenerated. Crystals of hæmatin.

In the uninjured kidney.—Some hæmorrhage into and around tubules. None in glomeruli. Some degeneration of renal cells.

The clinical evidence, as ascertained by cystoscopy, is as follows: On the uninjured side the urine had a specific gravity of 1020, and contained albumin, but no pus and no casts. On the affected side the urine had a specific gravity of 1005, and contained blood, much albumin, cellular detritus, and pus cells in quantity.

It is probable that the degenerative changes common to both kidneys in this case were the result of sepsis and fever, and such as might be occasioned by any septic wound unconnected with the kidney. It is also probable that some of the changes in the affected kidney were not unconnected with local sepsis in that organ. Cystoscopy was carried out sixteen days after receipt of the injury, and about a week before the patient's unexpected death from intraperitoneal hæmorrhage.

CYSTOSCOPY.

In this section is shown what attempts have been made by ureteral catheterization and colour tests to estimate the effect produced on the kidney function by such wounds as we have been considering.

It will be seen from the table that all the cases have been examined at least some days after injury. The *immediate* effect on the function of the kidney is not dealt with here. I have not been able to see the cases sufficiently early to be able to say whether secretion is temporarily abolished, as has been suggested by surgeons working at the clearing hospitals.

Cystoscopy may be resorted to in cases of injury to the kidney and ureter with the following objects in view: (1) To determine the effect of a wound on the function of the injured kidney. (2) To determine the presence and condition of the kidney of the opposite side. (3) To determine whether the injury is confined to one kidney, and if so, which; cases have occurred in which both kidneys have been wounded by a missile passing transversely. (4) To determine the extent of the injury in wounds of the ureter. (5) To determine by the aid of the ureteral catheter, combined with radiography, the position of retained missiles relative to the kidney or ureter.

Cystoscopy was carried out in 14 cases of this series. The cases investigated as regards the function of the damaged organ may be divided into the following classes (see Table, p. 260):—

1. *Those in which rapid recovery took place.*—In *Case* 8, the bullet was proved by operation to have passed through the kidney near the hilum. The urine, which contained blood on the patient's admission to hospital, was normal eight days after injury. The specific gravity of the urine from each kidney was 1015, and each specimen was free from blood, pus, and albumin.

In *Case* 12, a bullet had apparently passed through the kidney. Three weeks later the affected kidney was functioning as well as its fellow of the opposite side. Indigo-carmine appeared in equal quantities, and at the same moment, on both sides. There was a trace of albumin in both specimens, but as many of these patients run a moderate temperature, probably from sepsis, too much importance need not be attached to this.

2. *Those in which disturbance of function was indicated by a diminished specific gravity on the affected side.*—For many years I have attached much importance to the estimation of the relative specific gravities of the urine from each side in kidney cases.[3] I have found that in the unilateral affections of the kidney common in surgical practice, a diminution of the specific gravity in the urine from the affected kidney is of very usual occurrence. In tubercle of the kidney,[4] for instance, in both early and late cases, this sign is hardly ever absent; it does not necessarily mean a seriously diseased organ, as it occurs so early that very little damage has as yet been done to the kidney. It also occurs in some, but not all, cases of renal calculus. Even a small stone may produce it. Some years ago[3] I removed an oxalate stone weighing eight grains from the pelvis of the kidney of a young lady. The specific gravity of the urine on the affected side was 1005, as against 1015 on the opposite side. I have had many such cases since. In that just mentioned, and in similar cases on which I have since operated, there was no evidence whatever

of any but the most trivial and temporary damage to the kidney. In tumours of the kidney[5] this sign is also often present, even when the growth is comparatively small and much healthy kidney substance is present. In pyelonephritis, pyonephrosis, and hydronephrosis, the specific gravity of the urine on the affected side is likely to be low, but here extensive disease is present. In some cases the diminished specific gravity is due to reflex unilateral diuresis from irritation. This is particularly the case with small irritating calculi. There is often in these cases obvious increase in the rate of flow from the ureter of the affected side. In other cases the diminished specific gravity appears to be due to inability of the kidney to separate the solid constituents of the urine from the blood in normal quantity.

In cases of injury to the kidney I have not been struck with any decided increase in the vigour or rate of the ureteral jets; in some, indeed, the flow has been less in quantity and the jets have been more sluggish than normal. A diminished specific gravity on the side of the injury was present in the following cases of the present series. In *Case* 4, it was **1016** on the affected side, as against **1022** on the sound side; in *Case* 11, it was **1005** as against **1010**; in *Case* 13, **1015** as against **1025**; in *Case* 14, **1005** as against **1020**; in *Case* 19, **1015** as against **1020**; and in *Case* 39, **1005** as against **1010**. These cases are obviously too few in number from which to draw definite conclusions, but they are sufficiently striking to suggest a line of investigation in connection with the subject under discussion.

3. *Those in which disturbance of function was indicated by some alteration in the permeability af the kidney to dyes, such as indigo-carmine.*—Disturbance of function, as ascertained by colour tests, was sometimes found in cases in which the specific-gravity tests had given negative results. In these observations I have used indigo-carmine, in 2-grain doses, mixed with 2 drachms of sterile water. The mixture is injected deeply into the flank or buttock at the same time as catheters are introduced into the ureteral orifices. The time of appearance of the first trace of colour in the jets from the catheters is noted. Unfortunately it was not possible to continue the examination for long in many cases, owing to pressure of work in the theatre, but the results, incomplete as they are, are given for what they are worth.

In *Case* 11, besides a reduced specific gravity on the affected side, the blue colour of the indigo-carmine was less deep on that side. The colour was apparent on both sides fifteen minutes after injection, but throughout the observation it was of a lighter hue on the affected side.

In *Case* 13, both the specific gravity and the depth of colour were diminished on the affected side. The colour was apparent in both specimens twelve minutes after injection.

In *Case* 34, the specific gravicy was **1015** on both sides, but the colour took twenty-five minutes to appear on the affected side, as against twenty minutes on the sound side. This patient had passed through a severe illness, with fever and jaundice.

In *Case* 35—probably only a slight contusion of the kidney—the specific gravity was equal on both sides, and the colour appeared in both specimens in ten minutes. The colour was a little deeper, however, on the affected side.

In *Case* 39—a shrapnel ball injury—the colour was deeper on the affected

side. It came through on both sides in eighteen minutes, with the patient under ether. In this case a deeper colour was associated with a diminished specific gravity on the injured side.

The significance of these findings may perhaps be better appreciated after a reference to a recent paper by Tremolières and Caussade on "Nephritis Aiguës de Guerre,"[6] in which the authors give the results of their observations on the use of indigo-carmine as a test of renal permeability. They state that this dye appears in the urine twenty minutes after injection; after half an hour the colour is intense and at its maximum; from this time on the colour decreases regularly, until in six or seven hours the urine is again normal in colour. Exaggeration, diminution, or irregularity of elimination indicates pathological renal permeability. The authors divide acute war nephritis into two main groups:—

Group A: Cases with insidious onset, which on arrival at a hospital in the interior reserved for nephritis cases, showed albuminuria only, with no other clinical signs of nephritis. These cases had normal kidney function, including a normal elimination of indigo-carmine.

Group B: Cases with acute onset, which on arrival at the hospital showed, besides albuminuria, other signs of kidney trouble, such as hæmaturia, œdema, etc. These cases were subdivided into two types. The first included cases showing *increased* permeability to indigo-carmine, with retention of chlorides. The second type included cases of a more severe character, showing not only retention of chlorides, but also of urea; in these there was *decreased* permeability to indigo-carmine.

The cases I have so far examined have been, as I have stated, too few to draw conclusions from. In the light of the work of the authors just quoted, it may be that in those in which the permeability was greater on the injured side, the kidney had suffered less severe damage than in those in which the permeability was diminished. My own experience with indigo-carmine in civil and military surgery has been that the dye comes through in rather shorter time than that stated by these authors. I frequently find it in the urine in from ten to fifteen minutes after injection under ordinary circumstances in a normal subject. General anæsthesia seems to delay its appearance.

4. *Those in which abnormal constituents—such as blood, pus, albumin, and micro-organisms—have been found in the urine from the affected side.*— Albumin may be present on both sides in a patient suffering from sepsis, and is therefore only important from our present point of view when there is a greater amount on the affected side. A few blood cells are present so commonly as the result of even the most careful ureteral catheterization, that unless the number is large, no importance can be attached to them. If cystitis is present, a few pus cells may gain access to the catheter during its passage through the bladder, and this must be taken into consideration in judging of the condition of the kidney. Finally, contamination with micro-organisms is very likely to occur during the most careful cystoscopy. I always use ureteral catheters that will stand boiling; but the cystoscope is hard to sterilize.

Comparison of the findings on both sides, however, will give results

TABLE OF CASES IN WHICH THE FUNCTIONAL CAPACITY OF THE INJURED KIDNEY WAS INVESTIGATED.

Case	Nature of Injury	Length of Time since Injury	Specific Gravity		Indigo-carmine	Chief Abnormal Constituents on Injured Side
			Affected Side	Sound Side		
4	Injury to pelvis and cortex	Two months	*1016*	*1022*	—	Blood, pus, micro-organisms, epithelial casts
8	Perforating wound	Eleven days	1015	1015	—	Nil
11	Tangential wound (?)	Three weeks	*1005*	*1010*	Deeper colour on sound side	Nothing definite
12	Perforating wound	Three weeks	1005	1005	Same depth of colour on both sides	Streptococci and *B. coli*
13	Perforating wound	Four weeks	*1015*	*1025*	Deeper colour on sound side	Pus and streptococci
14	Tangential wound	Sixteen days	*1005*	*1020*	—	Blood, pus, streptococci
17	Tangential wound	Twelve days	1015	1015	Deeper colour on sound side	Blood
19	Perforating wound	Seven days	*1015*	*1020*	—	Blood
34	Tangential wound	Twenty-four days	1015	1015	Delayed on affected side	Nothing definite
35	Contusion	Seventeen days	1020	1020	Deeper colour on affected side	Nothing definite
36	Perforating wound	Three months	1010	1010	Same depth of colour on both sides	Nil
39	Perforating wound	Three weeks	*1005*	*1010*	Deeper colour on affected side	Albumin, pus, streptococci

of value. In *Case* 4, there were a few pus cells, numerous red cells, some epithelial cells, *B. proteus*, and Gram-positive cocci on the affected side. In *Case* 13, pus, streptococci, and cells from the renal pelvis were found on the affected side. In *Case* 14, blood, pus, streptococci, and cellular detritus were found on the injured side. In *Case* 17, blood, but no pus, was found on the affected side. In *Case* 30, blood, but no pus, was obtained from the injured side. In *Case* 39, pus cells and streptococci in considerable numbers were found on the affected side.

THE VALUE OF X-RAY EXAMINATION IN KIDNEY INJURIES.

In all our cases of kidney injury arriving at the base with retained foreign bodies, we have had stereoscopic radiograms taken. These have been of the greatest service in accurately locating the foreign bodies, and in enabling us to form an idea as to their course and the structures likely to have been injured during their passage. Mackenzie Davidson's method of localization has been used, and has proved accurate and reliable. Most of the cases here referred to have been *x*-rayed by Captain Gamlen; but Major Higham Cooper, Major Curtis Webb, and other radiographers have also given me valuable assistance; I am much indebted to these officers for their kind co-operation. In addition to the ordinary methods of localization. I have in several cases used the opaque ureteral catheter, passed into the pelvis of the kidney, combined with stereoscopic radiography, when the missile was thought to be in the vicinity of the kidney or ureter. In this way it has been possible to estimate with great exactitude the position of the foreign body relative to the kidney or ureter. I have, in a previous communication,[7] described this method, and given details of cases so examined. The following in the present series were investigated in this way.

In *Case* 8, already published,[7] a bullet was seen to be lying in the vicinity of the kidney. An opaque ureteral catheter was passed into the uppermost calyx. Stereoscopic radiograms were now taken. The base of the bullet was localized as lying in the line of the ureteric catheter and 1·8 cm. behind it. The apex pointed downwards and outwards, and was almost 2 cm. further away from the plane of the catheter. The bullet lay 5·7 cm. below the point of the catheter. With these measurements, we arrived at the conclusion that the foreign body was just outside the kidney, near the lower pole. Operation proved the correctness of this assumption.

In *Case* 19, two pieces of shell were seen lying anterior to the plane of the upper part of the ureteral catheter. The upper fragment was localized as lying 3·8 cm. anterior to the plane of the catheter, and therefore well in front of the kidney, probably in the liver. The lower fragment was localized as lying 2·2 cm. anterior to the plane of the catheter, and therefore probably just in front of the kidney. The patient was transferred to England without any attempt being made to remove the foreign bodies. He remains, a year after his injury, free from urinary symptoms. It is interesting to note that in the report made on his case in England, where he was again *x*-rayed, the fragments are assumed to be *in* the kidney.

In *Case* 14, the foreign body, a fragment of shell (see *Fig.* 195), was

localized as lying in the same plane as the ureteral catheter, on a level with its point, but nearer to the middle line of the body, probably at the inner margin of the upper pole of the kidney. Post mortem, it was found exactly in this position.

In *Case* 35, two fragments of metal were localized as lying 4 cm. and 1·9 cm., respectively, posterior to the plane of the ureteral catheter. They had entered from behind, and had caused slight contusion of the kidney, probably without actually touching it. The foreign bodies were not removed.

When we come to discuss urinary fistula, we shall see that use may be made of radiography to demonstrate the patency or otherwise of an injured ureter. *Case* 27 was investigated in this way, and will be described in due course.

RECONSTRUCTION OF THE TRACK OF THE MISSILE.

In most of the cases mentioned in this communication, an attempt has been made by sectional anatomy to reconstruct the track of the missile. It has been assumed that the foreign body generally takes a straight course. This assumption cannot be defended in all cases, as a missile striking a hard surface may be deflected. In these cases, a line drawn from the entrance wound to the point of deflection—a fractured bone, for instance—and from the point of deflection to the position of the foreign body or the exit wound, will indicate, as a rule, the course taken. Here *x* rays will afford valuable help.

When the foreign body has been localized by *x* rays, certain fallacies must be avoided. For instance, when a missile has entered a hollow viscus and passed on, it would be obviously absurd to imagine a straight course from the entrance wound to the position of the foreign body as localized by *x* rays. Similarly, where the missile has fallen into the peritoneal cavity, as in *Case* 18, a line drawn from the entrance wound to the position of the foreign body might be far removed from the track of the missile. It has also been objected that the line of the track varies according to the position of the wounded man at the time of receipt of the injury, and this must be admitted.

On the other hand, in connection with the area of the trunk now under consideration, the surgeon will gain valuable and interesting information, which will help him in dealing with the case, if he reconstructs the track on the assumption that a more or less straight course has been taken. Captain P. T. Crymble,[8] who first suggested the use of cross-sections for this purpose, has demonstrated that in many of his cases reconstruction of the track by him gave results not far removed from the true state of affairs as ascertained post mortem or by operation, and my own experience bears this out.

In transverse wounds in the lumbar region, one can, as in *Case* 6, determine with some prospect of accuracy which kidney is likely to have been wounded. The missile in this case, if it had taken a straight course between the entrance and exit wounds, would have missed the left kidney and have injured the right. In a case of severe hæmaturia without external hæmorrhage, the probability of the offending kidney being thus indicated would be of great service, failing cystoscopy, should operative measures be necessary. Notwithstanding all

that has been urged against the method, those who have used it are satisfied that in no other way can such useful information be obtained. The objections that all bodies are not alike, and that certain patients may be abnormal, do not, in my opinion, weigh against the obvious advantages.

For my own purposes I use a cross-section atlas of anatomy. A key figure shows the body divided into sections of a certain thickness. Each of these slabs is numbered, and at the corresponding number in the atlas the organs

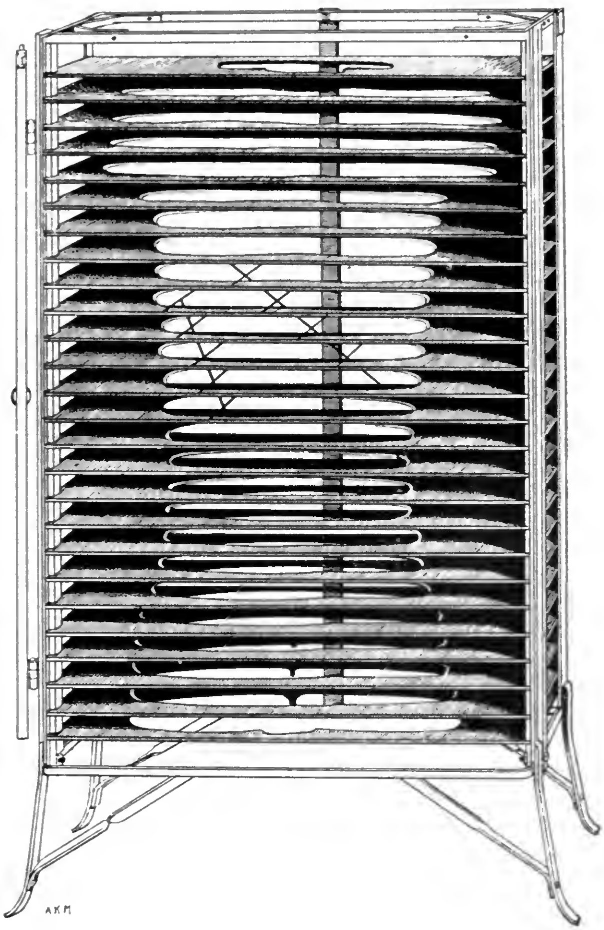

FIG. 196.—Diagram representing the frame described in the text. Each shelf corresponds to a plate in a cross-section atlas of anatomy, and the aperture fits the outline of the section at that level.

Two tracks of missiles are shown. The point where the line of the track passes through the space in each shelf is determined by passing a thread or wire across the space, and marking the spot where it is intersected by the line representing the track, as shown in *Fig.* 197, where the point of intersection lies in the kidney.

and structures are figured as they are found at that level. For use with this atlas I have had a frame with shelves made (*Fig.* 196). The frame supports the shelves, which are so arranged that each shelf corresponds to the upper surface of a section of the body at that level. Instead of each shelf having printed on its surface a drawing of the structures seen at this level, it has a large opening which just fits the drawing in the atlas. The circular opening, therefore, of this shelf corresponds to the contour of the body at that level.

When the shelves are placed in position in the frame, and one looks from above down, a hollow space like a mould of the body is seen, and a thread may be arranged so as to stretch from the point of entrance to the point of exit or to the location of a foreign body, anywhere in the hollow space. The foreign body may be slung in the proper position by threads or wires. The point at which the thread representing the track passes through the circular aperture in each shelf can easily be shown by cross-threads, with an ink mark at the points where they are intersected by the thread representing the track. If this is done in each segment, and the shelves are placed in turn so as to fit the plates

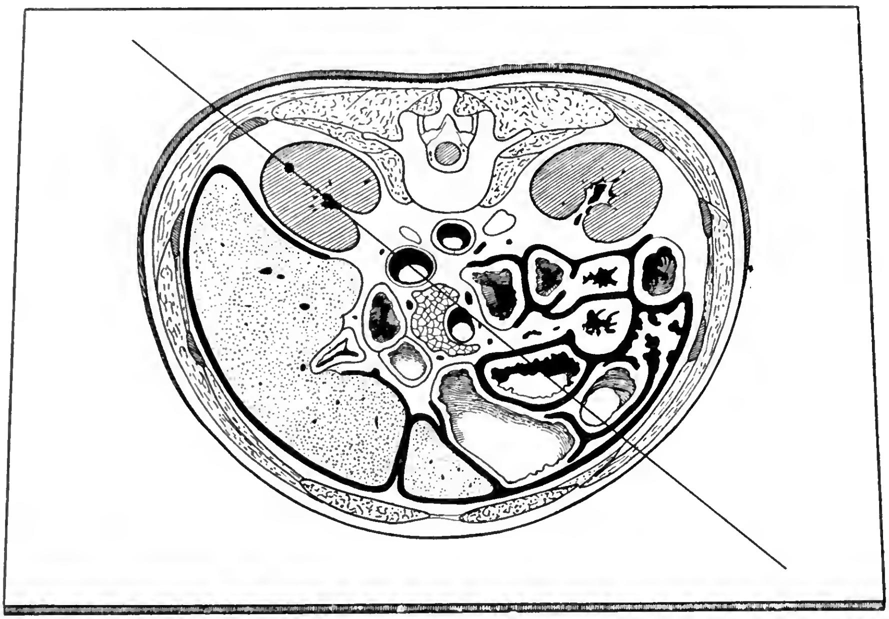

FIG. 197.—Diagram showing one of the shelves removed from the frame seen in *Fig.* 196, and fitted on to a cross-section in the lumbar region.

The line on which is marked the point where the track passes through the space need not be oblique as represented in the drawing, but may be made in any direction so long as it touches the line of the track.

in the atlas, the organs or structures penetrated will be seen at a glance (*Fig.* 197). This has proved to be a very convenient method of reconstructing the track.

Looking over the notes of the cases appended, it will be seen that the most usual route of approach of a missile to the kidney is posterior or postero-lateral, just below the ribs; the route through the chest wall comes next in order of frequency; transverse wounds come third; while, at any rate in the cases seen at the base, the route from before back through the abdominal cavity is the least frequent.

ASSOCIATED INJURIES.

In the cases seen at the base, the most frequent associated injury has been a wound of the *pleural cavity*. In 17 out of 42 cases (40 per cent), the missile reached the kidney by way of this cavity. In 7 cases hæmothorax was definitely diagnosed; in 3 an empyema formed; in 1 hæmoptysis was present; and in the remaining cases the missile was presumed to have passed through the pleural cavity from a study of the anatomy of the track.

The *liver* is very frequently injured in wounds involving the right kidney. In 14 cases (33 per cent) the missile had probably passed through or injured the liver, and 2 of these developed an abscess around a retained foreign body. In most cases the track through the liver gave rise to no urgent symptoms during the patient's sojourn in France.

The *spleen* has fairly frequently been found damaged in injuries of the left kidney treated at the clearing stations. In only 1 case of the present series was this complication found.

The *spine* is injured in a fair proportion of cases. In 6 out of our series of 42 (14 per cent) there was definite evidence of associated spinal injury, and in 3 additional cases injury of the bones, but not of the cord, was suspected.

The *hollow viscera* were injured in 5 cases, as ascertained by operation: the colon in 3; the small intestine in 1; and the duodenum in 1.

The *pancreas* was found injured in 1 case.

The *diaphragm* is perforated in those cases in which the missile passes through the pleural cavity on its way to the kidney. In most of the cases seen at the base no treatment of this structure has been required.

The *peritoneal cavity* may be entered by the missile without obvious damage to hollow viscera, as in *Case* 18, in which the bullet was found free, and in *Case* 23, in which there was an aperture through which the missile had disappeared after crossing the line of the ureter.

SIGNS AND SYMPTOMS.

The signs and symptoms of injured kidney are as follows:—

Hæmaturia, which may be microscopic, moderate, or profuse. It is well in a doubtful case to ascertain that the blood is not coming from the bladder, as is so frequent in associated injuries to the spine with hæmorrhagic cystitis. I have seen splashes of hæmorrhage scattered over the bladder wall in a case in which a piece of shell had injured one of the lumbar vertebræ without involving the cord; until cystoscopy had revealed hæmorrhage into the mucous membrane of the bladder, the case was thought to be one of injury to the kidney or ureter. It is well also to bear in mind the possibility of hæmorrhagic cystitis unassociated with spinal injury, as I have seen several examples in unwounded men coming down from the front. Other causes of hæmaturia independent of injury will, of course, suggest themselves to the surgeon.

Urinary fistula will be dealt with later. In some cases a watery discharge from the wound has been mistaken for urine. A little care is sufficient to

prevent such an error. It is well to test such fluid with litmus paper, and to examine for the characteristic urinous odour from the dressings.

In addition to these special signs indicating renal or ureteric injury, the following are often present:—

Shock is frequently met with, and may be due to accompanying injury to the abdominal viscera, thorax, or spine.

Anæmia after profuse loss of blood is often very marked in a patient when he reaches the clearing station or the base.

Vomiting was reported in about 25 per cent of the cases. It may have been more frequent. It occurs in uncomplicated cases, but is much more likely to be present when the abdominal viscera have also been injured.

Tenderness and rigidity of the abdominal wall are present in most but not all of the cases. These symptoms may be due to injury of the peritoneum, injury to the abdominal viscera, injury to the pleura and diaphragm, blood in the peritoneal cavity, or retroperitoneal hæmatomata. In some of the reports sent down with the patients from the clearing stations, the definite statement has been made that on arrival there, tenderness and rigidity have been absent.

Abdominal distention is frequently met with, as might be expected. In those cases associated with spinal injury it is very likely to be present.

Dullness in the flanks has occasionally been seen.

A tumour in the flank, due to perirenal extravasation of blood, is sometimes palpable. This may be a sign of importance in certain transverse wounds in which it is not easy to locate the kidney affected.

Fever may be present, and is due to the fact that many of the wounds are septic.

DIAGNOSIS.

The diagnosis of a wound of the kidney or ureter will be made by attention to the signs and symptoms just enumerated In *Cases* 22 and 30, injury to the kidney was quite unsuspected until the occurrence of secondary hæmorrhage—in *Case* 22 into the retroperitoneal tissues, and in *Case* 30 into the bladder. For this reason it is well, in all wounds of the loin, to examine the urine with the microscope for the presence of blood. In some cases the diagnosis of injury to the kidney has been made during an operation in the loin region, or in the course of laparotomy for injury to the abdominal organs. In these cases the actual damage to the kidney has been seen or felt. Attention may be drawn to the fact that an apparently trivial wound in the loin may have involved the kidney. I have seen a piece of shell in the kidney of a patient who died from other causes, and in whom the kidney was never suspected during life.

COMPLICATIONS.

The three great complications of injuries to the kidney and ureter are *sepsis*, *secondary hæmorrhage*, and *urinary fistula*, referred to in detail below. The following are also sometimes present:—

Retention of Urine.—This was present in 8 cases, in 6 of which it was due to associated spinal injury.

Cystitis.—This is a frequent complication. It is due to the presence in the bladder of infected blood which has come from the wound in the kidney. In cases associated with spinal injury it is almost certain to occur.

Fæcal Fistula.—This complication was present in 2 cases. In *Case* 15, the fistula soon closed, and the patient, who subsequently had nephrectomy performed for secondary hæmorrhage, made a good recovery. In *Case* 41 also, nephrectomy was performed for secondary hæmorrhage; this patient died a few days later from sepsis. The presence of a fæcal fistula would appear to predispose to secondary hæmorrhage.

Sepsis.—This complication is present in most war wounds. It is likely to occur in kidney wounds for the following reasons :—

1. A large amount of blood is thrown out into the loose perirenal connective tissue. Both blood-clot and loose connective tissue are notoriously favourable to the development of infection, once micro-organisms are introduced.

2. Owing to the absence of collateral circulation in the kidney, a certain amount of gland tissue in the immediate vicinity of the wound dies. This dead tissue forms a suitable medium for the growth of micro-organisms.

3. If the adjoining colon is bruised or damaged, the entrance of intestinal micro-organisms, or fæces, transforms the wound at once into a septic one.

Secondary Hæmorrhage.—Bleeding from a wound of the hilum or of the kidney itself may take place (*a*) into the peritoneal cavity; (*b*) into the perirenal retroperitoneal tissues; (*c*) through the wound in the parietes; and (*d*) into the bladder by way of the ureter.

a. Bleeding into the peritoneal cavity may occur in the early stages, but is not commonly met with at the period when the patient reaches the base.

b. When blood infiltrates the retroperitoneal connective tissue, it often gives rise to a huge mass which, on exploration, looks like a bullock's heart. This mass moves with the kidney during respiration, and sometimes becomes rounded off, so that an operator meeting with it for the first time might mistake it for a greatly enlarged kidney. To reach the kidney it is necessary to peel off this overlying infiltrated fleshy mass.

c. Hæmorrhage is sometimes revealed by bleeding through the external wound, though the urine appears to the naked eye to be clear. This may be due, as Sir George Makins suggests,[9] to a fragment of kidney substance obstructing the ureter, or, more commonly, to blocking of the ureter with blood-clot.

d. In most of the cases of injury to the kidney that I have seen, blood in greater or less quantity has been present in the urine. In wounds confined to the pelvis of the kidney or the ureter, however, this sign may be absent, or at any rate may pass unnoticed by the patient or his medical attendant. In *Case* 30, the first indication of any injury to the kidney was severe hæmaturia twelve days after receipt of the injury. In *Case* 22, there was no history of hæmaturia, but no microscopical search was made for it : a fatal hæmorrhage took place into the retroperitoneal tissues. Many of the patients gave a history of having noticed blood in the urine shortly after

being hit. In others, a note accompanied the patient saying that the specimen removed by catheter at the clearing station contained blood. In the cases in which the urine was microscopically examined at the base, blood was present in almost every one. In addition to blood, pus and micro-organisms were frequently present, even when no catheter had been passed. As has been pointed out, it is well to exclude cystitis as a possible cause of hæmaturia. In *Case* 31, though a vessel at the hilum was alone injured, blood was present for nine days after injury. This had completely disappeared on the eleventh day, when a final microscopical examination of the urine was made.

If the blood is poured out into the ureter in large quantity, clotting is likely to take place when the blood reaches the bladder. This will there give rise to difficult micturition, and to hypogastric or penile pain. In addition, cystitis is very likely to follow. The passage of clots or of fragments of kidney down the ureter may give rise to severe renal colic. The amount of blood in the urine varies from a microscopical quantity to a deluge sufficient to blanch the patient. The duration of the hæmaturia in patients who eventually recover without surgical interference varies from a few days to a month or more. During its continuance, there is much variation in the amount of blood passed from day to day. The urine which is deeply tinged one day may be comparatively clear the next. This variation may be due to temporary obstruction of the ureter. If clot is present in the bladder, ureter, or pelvis of the kidney, the urine may be stained though no active bleeding is in progress.

In cases in which the bleeding persists after the tenth or twelfth day, some anxiety will be felt as to the possibility of a large secondary hæmorrhage. In some cases we have been obliged to evacuate our patients to England with blood still present in the urine, and we have not been able in all to ascertain whether complete recovery has taken place or not. In one, nephrectomy for hæmorrhage was performed after the patient had been for some time in a home base hospital.

Secondary hæmorrhage of a severe type took place in 9 cases out of a total of 42 reaching the base. Leaving out of the total 2 cases in which the ureter alone was involved, this gives a secondary-hæmorrhage percentage of 22 in the cases in which the surgeons at the clearing stations felt justified in adopting conservative measures. In some of these the injury appeared to be of quite a trivial nature, as in *Case* 25, in which a simple perforating wound by a bullet was followed by repeated attacks of hæmorrhage, finally requiring nephrectomy. In 8 out of the 9 cases nephrectomy was performed, with 3 deaths ; in the ninth case nephrectomy was not considered necessary, and the patient died from other wounds. In *Case* 14, intraperitoneal secondary hæmorrhage took place, and was followed by death ; the hæmorrhage was, however, unconnected with the kidney or its vessels.

The date of onset of secondary hæmorrhage in these nine cases was as follows : third day in *Case* 21, seventh day in *Case* 24, tenth to fifteenth day in *Cases* 9, 15, 18, 30, and 41, and four weeks and one month after injury in *Cases* 25 and 32 respectively. In *Case* 9, bleeding took place into the bladder ; in *Cases* 18 and 22, into the perirenal tissues ; in *Cases* 24, 25,

and 30, into the bladder; and in *Cases* 32 and 41, through the external wound. The nature of the missile was as follows: shell in 6 cases, bullet in 2, and shrapnel ball in 1. Of the 6 cases in which the wound was produced by fragments of shell, 3 died; both cases wounded by bullet recovered; the case wounded by shrapnel ball died from other injuries.

The history of a case of moderate secondary hæmorrhage is well exemplified in *Cases* 15 and 25. In these, several attacks of varying severity occurred, with intervals of freedom; in both cases the surgeon held his hand in the hope that each attack would be the last, and in both cases nephrectomy was finally performed. In the remaining cases, the first or second attack was so severe that radical measures were at once adopted.

From an analysis of the cases I have just mentioned, it is evident that while shell wounds are more likely to cause secondary hæmorrhage, bullet wounds, producing an apparently trivial injury, are not devoid of danger.

Factors Contributing to Secondary Hæmorrhage.—Secondary hæmorrhage in the kidney, as in other parts of the body, is due to failure of the natural processes of repair which tend to arrest bleeding, viz., retraction of the vascular coats, formation of internal and external clot, and final cicatrization of the bleeding vessel or vessels. Here, as elsewhere, the determining factor is the presence of sepsis. There are, however, certain other circumstances which contribute to the risk in the case of the kidney: (1) The blood-supply is out of all proportion to the size of the organ; (2) The blood-pressure is liable to frequent and sudden changes; (3) Collateral circulation being absent, the necrotic areas which form round the track of the missile tend to perpetuate local sepsis.

Treatment of Secondary Hæmorrhage.—It must be admitted that the treatment of secondary hæmorrhage from the kidney or its vessels is highly unsatisfactory. The canon of surgery in other parts is to expose the bleeding vessel and tie both ends in as healthy a spot as available. Even if the vessel in the kidney giving rise to the bleeding could be identified and dealt with, the inevitable necrosis of its area of supply would be a matter of importance, should sepsis extend to it. There seems, up to the present, to have been no middle course between temporizing and ablation of the organ itself. Sir George Makins,[9] in an article dealing with gunshot wounds of the solid abdominal viscera, referring to cases seen by him at the base, says: "In none of these cases was a limited operation justifiable . . . This opinion is founded on the fact that a partial operation is not likely to remove the primary cause of the bleeding, viz., infection. Hence it is not right to expose a patient already grossly anæmic to the risk of a fresh hæmorrhage from a sutured or partially resected organ."

If the surgeon is satisfied that the patient has another sound efficient kidney, his safest course will probably be to remove the offending organ. Is he, however, justified in assuming that such is the case? I have learnt by sad experience in civil practice that even in a healthy-looking patient it is not safe to assume that there is a second competent kidney. Since I came to France, a number of men have been sent down to the base who, on being radiographed, showed renal calculi in one or other kidney. I have seen one case of tuberculous kidney and two cases of pyonephrosis in men otherwise

perfectly fit. I have seen a kidney removed for hæmorrhage, after nephrotomy for stone, and have examined a patient who had but a thin sac remaining of his kidney on one side. With these cases in my mind, and there must be many such in any large body of men, I do not feel justified in recommending removal of a damaged kidney without any knowledge of the state of the opposite one.

For this reason, I would strongly recommend that some attempt should be made, whenever this is possible, even under the adverse conditions of war, to ascertain the condition of the unwounded kidney. An injection of indigo-carmine, followed in a few minutes by examination with an ordinary observation cystoscope, will give information of value to the surgeon, should he be called upon to interfere in a case of hæmorrhage at a later date. Most cases of wounded kidney are sufficiently free from bleeding at one time or another to make this a matter of no great difficulty.

If the bladder is full of clots, the difficulties of cystoscopic examination are almost insuperable. A method which has been carried out by Major Grant Andrew in similar cases in civil practice is well worth a trial. He performs a suprapubic cystotomy, turns out the clots, and examines the interior of the bladder with a Fergusson's vaginal speculum. The jets from the ureters are now seen with the greatest ease. The bladder is subsequently sewn up.

Palpation and radiography may reveal the presence of a second kidney and give some information as to its size and shape, but will not give any idea as to its functional capacity. The method of opening the peritoneum while dealing with the damaged kidney, and passing the hand across to the opposite side to palpate the opposite organ, conveys so little information, and is attended with so much risk in a septic case, that few surgeons would care to adopt it. If, however, an abdominal operation has been performed at a clearing station, such information as can be gained by this method might be noted on the patient's field card. The segregator would be useless in severe hæmaturia. If the bleeding is coming through the wound in the parietes, and clear urine is obtained from the bladder, as in *Case* 41, the inference is that it comes from the uninjured kidney. An examination of such a specimen of urine would give valuable information.

I have carefully examined most of the kidneys removed, with a view to estimating what operation might be carried out short of a total extirpation. In some, the damage was so slight and the condition of the kidney in the neighbourhood of the wound so good, that I feel certain resection of the damaged part might have been attempted—e.g., *Case* 30 (see *Figs.* 191, 192). In one or two cases, the entrance and exit wounds in the trunk and in the kidney itself were so minute and so free from gross sepsis, that no harm could have resulted from a trial of conservative measures, provided that the operation had been performed before the patient had become severely anæmic. The primary cause of the bleeding is infection, but the septic area might be removed entirely, especially in the slighter wounds, by a wedge-shaped excision. It must be remembered, however, that any incision in the kidney may give rise to areas of necrosis from damage to blood-vessels (*Fig.* 198). Much judgement would therefore be required in deciding on a partial operation

in a given case. The fact, however, that partial excision for localized damage to the kidney has been successfully carried out at clearing stations is, I think, an argument in favour of a similar procedure in selected cases at the base. If hæmorrhage comes from a vessel before it enters the hilum, as in the case represented in *Fig.* 194, an attempt might be made to deal with it locally. Such cases will, however, occur so rarely that few surgeons are likely to have experience of the best method of dealing with them.

As to the best time to intervene in a case of secondary hæmorrhage, the condition of the patient and the frequency and severity of the attacks must be the guide. If bleeding is persistent after the tenth day, and of such quantity as to produce anæmia, too much time must not be lost in deciding on operation. If the surgeon elects to give partial nephrectomy a trial, this must be done early, and before the patient is blanched. A very severe attack of hæmorrhage at any period demands instant interference. Transfusion of blood, as in *Case* 32, ought certainly to be carried out if the patient is very anæmic.

In all cases, as soon as the damaged kidney has been dealt with, the bladder must be emptied of clots. We have found that this can be accomplished by a Bigelow's evacuator while the patient is on the table. Suprapubic cystotomy will rarely be required for this purpose.

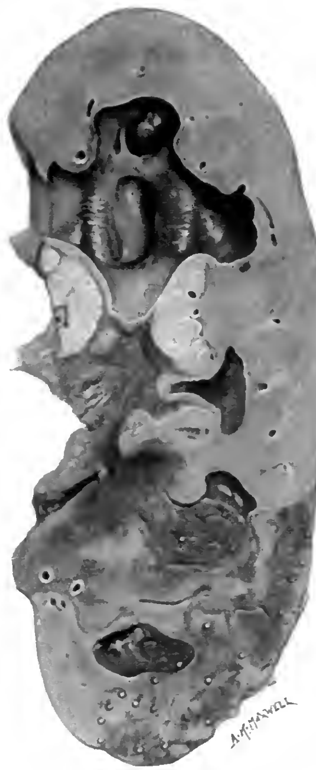

Fig. 198.—A kidney removed for secondary hæmorrhage three days after nephrotomy for stone. The dots represent suture holes. Such close suturing is unnecessary. Note the areas of necrosis produced by interference with the blood-supply—partly by section and partly by strangulation of blood-vessels by sutures.

As an alternative to indigo-carmine, I have recently been using phenolsulphonephthalein for the investigation of the functional capacity of the kidneys after injury. This is used as follows: One c.c. of a solution containing 6 mgm. of the drug per c.c. is injected intravenously. In one hour, 60 per cent of the total amount injected will be excreted, if the kidneys are healthy. If injected intramuscularly, the time of appearance and the time taken for elimination will be somewhat longer. In acid urine the colour will be a rich amber, in alkaline urine a permanganate pink. To ascertain the amount of the drug present in a given specimen of urine, the latter is made alkaline, and the depth of colour is estimated with a standard solution in a colorimeter. For further particulars the reader is referred to an article on "The Phthalein Test," by Rowntree and Geraghty.[10]

The two cases following, investigated by the phthalein test since this

lecture was delivered, bear so much on several of the points raised, that a short account of them may with advantage be given here.

Sergt. H., was wounded in the left loin by a fragment of shell on June 10, 1917. The fragment was removed from the lower pole of the left kidney at a clearing station. He was admitted to a base hospital under the care of Captain Palmer on June 11. Two days later he developed a urinary fistula, but this was almost dry when he was cystoscoped on June 28, eighteen days after injury. One c.c. of the solution described above was injected into a vein. The drug appeared in the urine from the injured kidney in five minutes, and in that from the uninjured kidney in six minutes. Specimens were collected by ureteral catheters for twenty-five minutes. The specimen from the right, uninjured, side was as follows: Sp. gr. 1005, flow sluggish, phthalein 1 per cent, urea 0·007 gm. per c.c., albumin more than a trace. That from the injured side was as follows: Sp. gr. 1015, flow free, phthalein 4 per cent, urea 0·012 gm. per c.c., albumin a trace. In this case the uninjured kidney showed very doubtful efficiency, and if an operation for secondary hæmorrhage had been required, it would have been unwise to have sacrificed the injured kidney, which appeared from the findings to be much the better of the two.

Pte. W. R., was wounded in the left loin by a large fragment of shell on July 7, 1917. The foreign body, which was 2½ inches long, was removed from the neighbourhood of the lower pole of the left kidney by Captain Meyer at a casualty clearing station. The lower third of the kidney was found "badly lacerated," and was treated by packing and B.I.P.P. There was no leakage of urine. On July 18, the urine was reported to be normal. When examined at a base hospital, there was a large granulating wound just below the twelfth rib on the left side posteriorly.

On July 23, 1 c.c. of phenolsulphonephthalein was injected into the muscles of the gluteal region. The bladder was emptied by catheter two hours later; 50 per cent of the drug was recovered from this specimen.

On July 24, i.e., seventeen days after injury, the urine was found free from albumin, pus, and blood, and the patient was cystoscoped. The bladder was found to be normal, and with no change in the appearance of either ureteral orifice. One c.c. of phenolsulphonephthalein was injected intravenously, after catheters had been introduced so as to collect the urine from each ureter separately. The patient was under an anæsthetic, and the drug appeared on both sides ten minutes after injection. The catheters were allowed to remain in the ureters for twenty minutes after the appearance of the drug. The following are the results of the examination. On the right side, 4·5 c.c. of urine were collected in thirty minutes from the time of introduction; this quantity contained 22·5 per cent of the total amount of phthalein injected. On the left side, 3·7 c.c. of urine were collected in the same time, containing 18·5 per cent of the total amount of phthalein injected. Allowing for the difference in amount of the fluid collected from the two sides, the percentage of phthalein in the specimens was almost identical. Similarly, the quantity of urea excreted per c.c. was found equal on the two sides. No appreciable leakage of fluid had taken place by the sides of the catheters while in the ureters.

The result of this investigation shows that a kidney with a badly lacerated lower pole had completely recovered its function seventeen days after injury. The only difference between the two sides was a slightly diminished output on the affected side.

I am indebted to Captain Keith, of Johns Hopkins University, for the estimations in these cases.

Urinary Fistula.—Urinary fistula is very likely to occur under the following conditions: (1) When the pelvis of the kidney is wounded; (2) When a laceration of the parenchyma extends so deeply as to involve the pelvis; (3) When the ureter is injured. Wounds of the body of the kidney of a perforating character are not likely to lead to leakage of urine, though

these may have passed through the infundibula or calices. Many cases of the present series may be presumed to have had such perforating wounds, but the number in which a urinary fistula has been present is extremely small, and in these it is probable that the missile had passed obliquely through the pelvis in addition to perforating the kidney. In *Case* 36, this may have happened. In *Case* 33, the foreign body was felt to be in the substance of the kidney, and had probably involved the pelvis as well; this foreign body disappeared later, possibly by way of the colon.

In the present series, 9, or possibly 10, of the 42 cases, had a leakage of urine from the wound in the parietes. Two of these were known to be due to injury to the ureter, as seen at operation, and in several it is stated that the wound in the body of the organ had extended to the pelvis. In the cases in which the kidney was removed and a through-and-through wound found, not involving the pelvis, no leakage was discovered. It is possible that a few drops may have exuded at the time of the injury, and that the infiltrated mass usually seen around the kidney was in part due to the irritation so produced.

The leakage may appear at once, when it may be presumed that the ureter or pelvis has been torn during the transit of the missile, as in *Cases* 1, 3, 4, and 5; or it may be delayed, when it may be presumed that sloughing of a portion of the wall has taken place as a result of the damage inflicted. In *Case* 27, for instance, a retroperitoneal hæmatoma was found at operation, but urine did not appear in the wound until a week had elapsed. The urine may, in a given case, accumulate, and may later reach the surface; but in the case just referred to a drainage tube had been inserted, so that a free passage was left for its escape. A leak immediately after injury is comparable to primary hæmorrhage from a wounded artery, and may be called *primary* leakage, while a leak occurring after an interval of days is comparable to secondary hæmorrhage from a damaged vessel, and may be called *secondary* leakage. In the latter case the missile has probably damaged the pelvis or ureter, a portion of which gives way later, exactly as in the case of an artery under similar circumstances. Leakage of urine may last for a few days only, as in *Cases* 1 and 5, or it may last for months, as in *Case* 4. The ultimate result will of course depend on the size of the opening and the amount of destruction. Complete division will require a plastic operation or nephrectomy.

In *Case* 3, a note accompanied the patient from the clearing station stating that the ureter was found divided below the pelvis of the kidney, and that blood and urine were found in the peritoneal cavity. It is improbable, I think, that *complete* division had taken place, as the leak ceased, though no attempt was made "to close it (the ureter), but a drain was inserted through the loin."

In *Case* 27, already referred to, for a time all the urine from the left kidney came through the lumbar wound, as ascertained by cystoscopy and ureteral catheterization. It was desirable here to determine, if possible, the amount of damage to the ureter. This was accomplished as follows: Collargol was injected by a ureteral catheter through the cystoscope into the lower end of the affected ureter. Radiograms were taken, and the result is seen in *Fig.* 199. It was found that some of the collargol had escaped from

the ureter into the surrounding tissues, but some had passed on to the pelvis of the kidney, distending it and the terminal calices. The deductions which we drew from a study of this radiogram were as follows :—

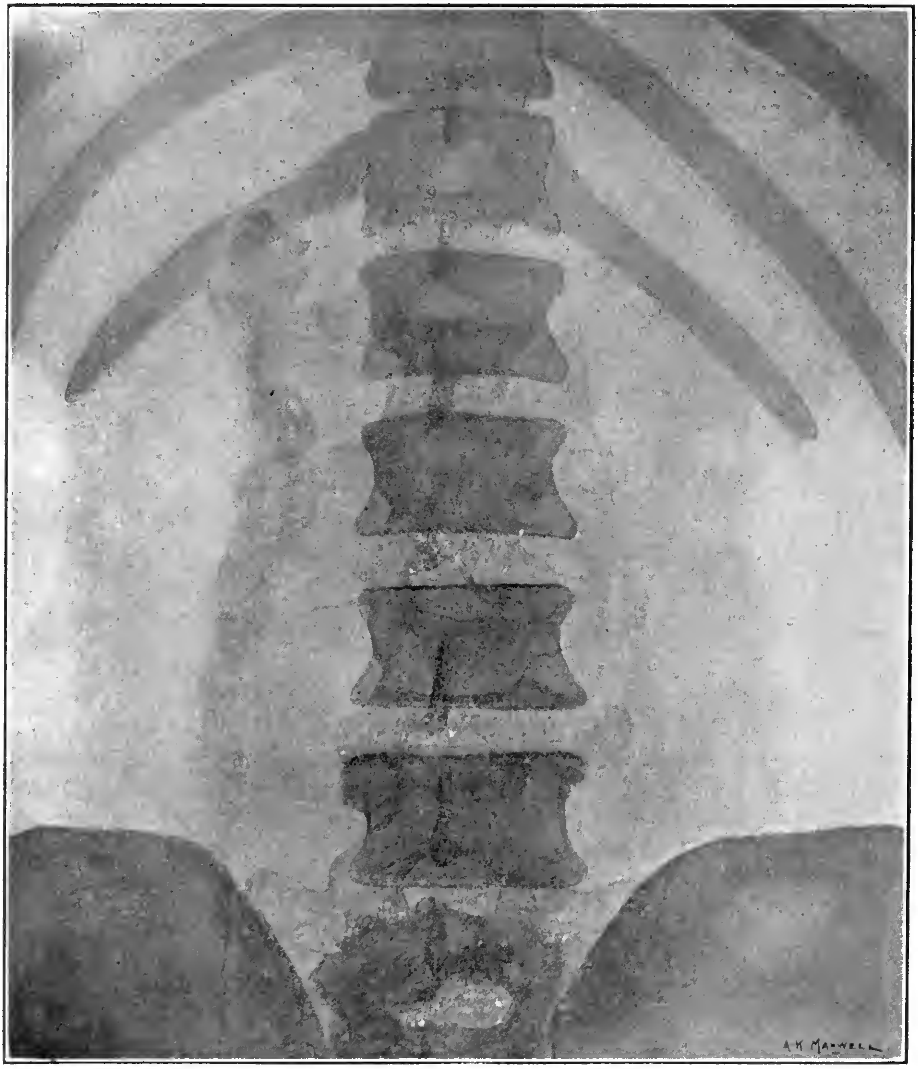

FIG. 199. *Case* 27. Collargogram of injured ureter. The collargol has escaped from a hole in the ureter, and has extravasated widely along the course of the duct. (Drawn from a radiogram.)

1. The hole in the ureter was of moderate size, and did not prevent the passage of the collargol to the pelvis of the kidney.

2. There was a cavity surrounding the ureter, filled with collargol which

had escaped from the rent in it. This was taken to be a cavity in the position of the former hæmatoma.

3. There was hope that the opening in the ureter would close. This hope was justified, as the urine ceased to flow from the wound six weeks after its first appearance.

We did not venture to locate the exact spot in the ureter at which the hole was situated, but the method just described might be of service in this respect in similar cases in future.

Although no case in the present series required any treatment for the leakage *per se*, it is not to be assumed, of course, that such results are always to be expected. Severe damage to either pelvis or ureter will necessarily involve a permanent fistula, failing successful plastic operation.

The after-histories of the cases which have undergone spontaneous cure will be interesting to follow, and hydronephrosis may safely be predicted in some, from contraction of the scar tissue in the tube itself or in the surrounding parts.

In *Case* 15, the urinary fistula was associated with a fæcal fistula, from damage to the colon. Both fistulæ closed in time, but nephrectomy for secondary hæmorrhage was required later.

Treatment of Urinary Fistula.—Very little is required in the way of treatment in these cases while at the base. If there is evidence of accumulation of urine in a cavity, a way of exit must be provided. Otherwise we have left them severely alone. The flow of urine over the wound surfaces does no harm. If the fistula persists, plastic operation or nephrectomy may be required.

CAUSES OF DEATH.

The chief causes of death in injuries to the kidney, as seen at the base, are sepsis and secondary hæmorrhage. Associated injuries were responsible for most of the deaths in the present series. Thus, 5 cases had spinal injury, 1 had injury to the pancreas and severe sepsis, 1 had multiple wounds and a hæmothorax, and 1 died from intraperitoneal secondary hæmorrhage unconnected with the kidney; 3 died from sepsis and secondary hæmorrhage from the kidney. This makes a total of 11 deaths while the patients were in France. *Case* 4 died in England about six months after receipt of his injury; the immediate cause of his death was pneumonia.

I cannot conclude without tendering my most sincere thanks to those medical officers who have so willingly assisted me in the collection and examination of these cases. I am also deeply indebted to Captain Herbert Henry for his assistance in working out the pathology, and to the Medical Research Committee for the services of their artist, Sergeant Maxwell, R.A.M.C., whose excellent drawings illustrate the text.

SHORT SUMMARY OF CASES.

Case 1.—Pte. S., under the care of Capt. Edye. Bullet wound. Admitted base hospital Sept. 28, 1915. Entry, mid-axillary line, left side, in ninth intercostal space. Exit, on level with first lumbar spine, half an inch from middle line, same side. Blood-stained urine per urethram and some urine from exit wound. Temperature normal and blood absent from urine two days later. Urine ceased to come from wound same time. Evacuated to England, doing well, Oct. 6, 1915.

Track of Bullet.—Probably as follows: pleural cavity, diaphragm, kidney, and pelvis of kidney. Possibly involved a transverse process.

Case 2.—Bugler S., under the care of Capt. Cole. Bullet wounds. Hit on Oct. 16, 1915. Admitted base hospital Oct. 19, suffering from hæmaturia, breathlessness, and præcordial pain. Multiple wounds. Compound fracture of left humerus, and wounds of both arms and both legs. There was an entrance wound, caused by a bullet, between ninth and tenth ribs in nipple line, very small, and partially sealed. Large wound, apparently superficial, in back, about one inch to right of vertebral column, opposite first and second lumbar vertebræ. Abdomen rigid. Patient died a few days after admission.

Post-mortem Report by Capt. Hopwood.—Right side of thorax full of blood-stained fluid, 3 pints. Right lung collapsed. No fluid left side. Recent pericarditis, some blood-stained fluid in pericardium. There was a hole through diaphragm in front, near costal margin. A ragged wound through lower border of right lobe of liver. This went right through the latter, and admitted two fingers. Abdominal cavity full of blood-stained fluid. Left kidney enlarged. Right kidney nearly torn in half, the space between the two halves being filled with dark blood-clot.

Track of Bullet.—Through an aperture in right nipple line, between the ninth and tenth ribs, avoiding right lung, through pleural cavity, diaphragm, right lobe of liver near lower edge, through kidney, and out through muscles of back at level of disc between the first and second lumbar vertebræ, a little to right of middle line. The wound of exit would just admit the little finger.

Case 3.—Pte. R., under care of Capt. Driberg. Bullet wound. Wounded Nov. 16, 1915. Entrance wound in front, left lower quadrant. Operation at a casualty clearing station. Eight perforations in three and a half feet of small intestine. Four feet resected. Left ureter found "divided" below pelvis of kidney. No attempt was made to repair it, but a drain was inserted through left loin. Blood and urine in peritoneal cavity. Abdomen closed. Drained.

Track of Bullet.—Anterior abdominal wall, small intestine, ureter.

Progress good; no urine passed by loin wound after arriving at base, about ten days after injury. Evacuated to England with urine free from pus and blood.

Case 4.—Rfm. McC., under the care of Capt. Driberg. Shell wound. Wounded Nov. 23, 1915. Five wounds in back, right side. Largest resembled a lumbar nephrectomy wound. Shell fragments had been removed at a casualty clearing station. Had much hæmorrhage from large wound after injury. Admitted base hospital, Dec. 2. The large wound exposed the kidney, which protruded when the patient coughed. Urinary fistula. Exposed kidney somewhat excoriated. On Jan. 4, 1916, a pocket of pus at the upper part of wound evacuated. Quantity of urine per urethram varied from 16 ounces to 65 ounces in twenty-four hours. On Jan. 10, very little leakage. Cystoscoped, Jan. 17: Ureteral catheters passed easily into pelves of kidneys. Before catheterization, urine could be seen issuing from right ureteral orifice, which was somewhat rounded in shape and slightly puffy. Urine from bladder: alkaline, sp. gr. 1012, contained ammonium urates, triple phosphates, many organisms, and a few bladder cells. From right ureter: alkaline, sp, gr. 1016, ureteral epithelium, a few pus cells, numerous red cells, numerous organisms, ammonium urates, triple phosphates, and some epithelial casts. From left ureter:

alkaline, sp. gr. 1022, no pus, sterile, blood cells (trauma of catheter). The organisms referred to were *B. proteus* and Gram-positive cocci. The pathological report was furnished by Capt. A. G. Ritchie.

Patient after evacuation to England was under care of Major Davies of 5th Northern General Hospital, who kindly reported progress of case. The urinary fistula had closed before evacuation. Major Davies reports on May 15, 1916: Empyema, subdiaphragmatic abscess, several operations. Free discharge of urine from fistula for weeks, ultimately closed, but patient contracted pneumonia in unaffected lung, and died on May 6, 1916. In a subsequent letter, Major Davies adds, "When he died, his urinary fistula and the chest openings had closed, and he had been out for several days, and seemed to be picking up rapidly when he contracted pneumonia in the sound lung which killed him in four days."

Track of Missile.—Lower part of pleura, diaphragm, pelvis of kidney.

Case 5.—Pte. M., under the care of Capt. Bryan. Rifle bullet. Wounded Feb. 18, 1916. Note from Capt. Dew, from a casualty clearing station, stating that the patient had an injury to the kidney, that there was a slight trace of blood and albumin in the urine, and a urinary fistula, and that the general condition of the patient was good. On admission to base, a small entrance wound was found 2 in. to the right of first lumbar spine and 4½ in. above the level of the anterior superior spine of the ilium. Exit wound over right lower ribs (eleventh). No fistula. Slight rigidity right iliac region. Slight dullness right lower chest. Some pain on coughing. *X* rays show fracture of eleventh and twelfth ribs. Evacuated to England on Feb. 29, doing well. This was evidently a wound of the pelvis of the kidney.

Track of Missile.—Posterior abdominal wall, kidney, peritoneal cavity, liver pleura, chest wall.

Case 6.—Pte. A., under the care of Capt. Driberg. Bullet wound. Wounded March 9, 1916.

Probable Course of Missile.—Through muscles of posterior abdominal wall, external to left renal region, across spinous process of twelfth dorsal vertebra, through outer part of right kidney, through right lobe of liver, diaphragm, and pleura, probably missing lung, then through chest wall and right upper arm.

Hæmaturia was present. There was no pus in the urine, which was alkaline, sp. gr. 1016, and contained red blood cells and triple phosphates. Empyema. No hæmoptysis. Frequency of micturition. Bullet casing and wood from rifle removed from arm. No bile in urine and no jaundice. An abscess formed in liver and was drained. A good deal of necrosis of liver substance.

This was a transverse wound which, from its course, apparently just missed the left kidney but wounded the right one.

Case 7.—Pte. J. B., under the care of Capt. Bryan. Shell wound. Wounded on March 14, 1916. Entrance wound, right side, level with disc between twelfth dorsal and first lumbar vertebræ in posterior axillary line. Also wounds over right pubic spine, right buttock, fold of buttock, and right thigh. Admitted to base hospital March 17. On March 20, laminæ of eleventh and twelfth dorsal and of first and second lumbar vertebræ removed, and shell fragment extracted from left side of theca between the eleventh and twelfth dorsal vertebræ. Two nerves were found divided. Urine contained blood and pus when catheter was used on March 18. The wound involved right eleventh rib and tip of twelfth. On March 21 abdomen full and tender. Paraplegia. Shell did not strike kidney itself. The patient died.

Post-mortem.—Both kidneys enlarged and congested. Ureters dilated but not thickened. On the upper pole of kidney of right side, between capsule and cortex, a hæmatoma. Beneath this an ecchymosed wedge-shaped area, with base uppermost, in the cortex and just involving pyramids.

Case 8.—Pte. M., under the care of Major West. Bullet wound. Date of wound, March 15, 1916. After being hit, a good deal of pain on breathing. Blood in urine.

No vomiting. Right side of abdomen rigid above umbilicus. Entrance wound, just behind mid-axillary line, lower part of chest.

Track of Bullet.—Chest wall, pleural cavity, diaphragm, peritoneal cavity, liver, and kidney.

With opaque ureteral catheter in position, and radiography, bullet located behind kidney or ureter at level of lower pole. On March 28, bullet removed from this situation. The bullet had passed through the kidney from front to back near hilum. Except for the track of the bullet the kidney looked healthy. Cystoscopy: Urine from both sides was normal, sp. gr. 1015. Complete recovery.

Case 9.—Rfm. W., under the care of Major West. Bullet wound. Date of wound, March 17, 1916. Through-and-through wound.

Track of Bullet.—Muscles of right side of back, transverse process of first lumbar vertebra or just above this, kidney, liver, peritoneal cavity, chest wall.

Capt. Taylor, of a casualty clearing station, saw him on March 18, and noted the following: Marked hæmaturia, vomiting (once), pulse 120, and feeble. Patient pale and cold. Abdomen tender and rigid. Laparotomy by Capt. Taylor same day: Blood in abdominal cavity, right lobe of liver perforated, colon bruised on inner side, œdema round duodenum, but no lesion or perforation of abdominal viscera. Under surface of liver still bleeding. Packed with gauze. Wall closed in layers. Four days later, urine clear; omentum protruded, replaced under anæsthetic. March 28, urine blood-stained. March 31, severe hæmaturia, blood-clots, vomiting, anæmia. Same day, nephrectomy. A large mass of infiltrated flesh-coloured perirenal tissue. An opening into peritoneal cavity found, and portion of liver projecting into nephrectomy wound. The opening was large. Bullet went through kidney close to hilum. Patches of yellowish-white colour at bases of pyramids opposite wound in kidney. Apices of all pyramids pale, and patches of yellowish white in renal columns between the affected pyramids. From small entrance wound, a streak of white extended outwards. Exit wound, a round irregular opening with a margin of whitish yellow round part of circumference. April 13, large clots washed out of bladder. Well-marked general cystitis. Urine, after operation, averaged 50 to 60 ounces per diem. Recovery.

Case 10.—Pte. C., under the care of Major West. Bullet wound. Wounded March 18, 1916. Admitted base hospital, March 20. Complete paraplegia below level of iliac crests. Hæmaturia. Died April 2.

Short Report of Post-mortem.—Entrance wound, right side. No exit. Small left hæmothorax. Some collapse left lung. Right kidney wounded at upper pole, and spinal cord divided at level of twelfth dorsal vertebra.

The notes of this patient are incomplete.

Case 11.—L.-Cpl. B., under the care of Capt. De la Cour. Bullet wound. Wounded March 21, 1916. Range 300 yards. Stooping at time. Passed water twenty-seven hours after being wounded, and noticed that it was bright red. Wound of entry small, aseptic, 12 cm. to right of middle line of back and ½ cm. above crest of ilium. Bullet, pointing down, localized as lying 16 cm. from back, about 9½ cm. from mid-line in front, same side, and 10 cm. below level of second costal cartilage. Admitted to base hospital on March 23. Hæmaturia. Abdomen rather full and tympanitic. Very acute tenderness over liver. Some rigidity, right side. No vomiting. Temperature 101·2°, pulse 94, respirations 30. Has had old bronchitis. Bullet appears to have injured posterior border of right kidney, and the liver. Urine remained slightly stained until April 9, i.e., about nineteen days. Quantity of urine averaged 40 to 50 ounces in twenty-four hours. Bullet was judged to be in vicinity of diaphragm. Cystoscopy, three weeks after injury: Right ureteral orifice, a little puffy, with slight congestion around. Anuria on right (affected) side for several minutes after passage of ureteral catheter. Flow from left side free from moment of introduction of catheter. Indigo-carmine came through on both sides fifteen minutes after injection into buttock. Colour deeper on uninjured side. Specimen from right side: sp. gr. 1005,

acid, clear, trace of albumin, renal cells and epithelial casts, ureteral epithelium, no pus, no blood. Specimen from left side : sp. gr. 1010, acid, clear, trace of albumin, hyaline and epithelial casts, renal cells, ureteral epithelium, oxalate of calcium crystals. The patient was discharged to England in good condition.

Case 12.—Sergt. H., under the care of Major West. Bullet wound. Wounded while standing, on March 20, 1916. Range about 300 yards. Seen by Capt. Meyer at a casualty clearing station, who sent notes as follows to base : " Pulse 128, temperature 97°, no abdominal rigidity, vomited twice, very marked hæmaturia, which ceased in two days. Lost a good deal of blood by external wound." Admitted base hospital, March 24.

Track of Bullet.—Abdominal muscles, peritoneal cavity, omentum, descending colon(?), left kidney, and posterior abdominal wall. Through-and-through wound.

Had cystitis, although no catheter had been passed. Cystoscopy, April 11 : General cystitis. Indigo-carmine injected into buttock appeared on both sides in about fifteen minutes, under ether. Specimens from right side : sp. gr. 1005, trace of albumin, no blood, a few pus cell (?), cells from ureter, no micro-organisms. Left (injured) side : sp. gr. 1005, trace of albumin, blood cells, no pus cells, cells from pelvis of kidney and from tubules, *Streptococcus pyogenes* and *B. coli*. Recovery.

Case 13.—Pte. J. W., under the care of Major West. Bullet wound. Wounded in erect position at a range of about 500 yards on April 18, 1916. Entrance wound, right side, level of tenth dorsal spine, posterior axillary line. Bullet located by *x* rays, lying 2·4 cm. from middle line opposite fourth lumbar vertebra and 1 cm. from the plate on right side. Note from Capt. Stevenson of a casualty clearing station : " On admission, vomiting, hard rigid abdomen. Decided to wait before operating. Marked hæmaturia, which is improving. Still has attacks of pain in right side, probably due to blood-clots in ureter. Hæmaturia for about a week. Hæmothorax, right side. Some cough. No hæmoptysis." Admitted base hospital, April 22. No abdominal symptoms. Urine contains blood and pus. April 27, no visible blood. April 30, laboratory reports blood and pus. May 12, a few red blood cells and much pus, also very numerous streptococci and a large Gram-positive bacillus. Quantity of urine, 50 to 60 ounces in twenty-four hours.

Track of Bullet.—Right side, chest wall, pleura, lung, diaphragm, peritoneal cavity, liver, kidney, and erector spinæ.

Had slight fever for about a week. Cystoscoped, May 16 : Slight degree of cystitis. Indigo-carmine came through twelve minutes after injection. Colour deeper on left or uninjured side. Flow apparently more on left side, but some escaped by the side of the catheter on the right. Specimen from right side : acid, sp. gr. 1015. *Streptococcus pyogenes*, pus, renal cells from tubules, no casts. From left side : acid, sp. gr. 1025, sterile, pus cells (?), hyaline casts, accidental blood. Patient made a good recovery.

Case 14.—Pte. W. C., under the care of Capt. Kelly. Bomb wound. Accidentally wounded, Feb. 22, 1916. When admitted to a casualty clearing station was in a collapsed condition. Had retention of urine. Specimen removed by catheter contained blood. This diminished, and was slight in amount on Feb. 24. Admitted base hospital Feb. 25. In addition to slight wounds of extremities, there was a small entrance wound on left side of back, 4·2 cm. above highest point of iliac crest and 9 cm. from mid-line, opposite interval between second and third lumbar spines. Foreign body retained. Hæmaturia ceased a few days after admission. He had slight fever, but this subsided in a few days. *X* rays showed a small foreign body 4·4 cm. from skin of back and 3·25 cm. from middle line just below lower border of last rib on left side. There were two smaller fragments, evidently quite superficial. An opaque ureteral catheter was introduced on March 9, and stereoscopic radiograms were taken. The two small pieces of shell were well behind the opaque catheter. The larger one was in the same plane as the ureteral catheter and on a level with its upper end, but much nearer the mid-line. The foreign body was located as lying near the inner margin of the upper pole of the kidney. On introducing the cystoscope,

before ureteral catheterization, a clot of blood was seen at the mouth of the left ureter. Specimens from right side: acid, sp. gr. 1020, urates, albumin, a few blood cells (trauma of catheter), no casts, no pus cells, *Staphylococcus pyogenes aureus*. Left side: acid, sp. gr. 1005, slightly cloudy, stained with blood, loaded with albumin, pus cells in quantity, cells from pelvis and ureter, much cellular detritus, *Staphylococcus pyogenes aureus* and *Streptococcus pyogenes*.

The patient died, unexpectedly, on March 17. The post-mortem was made by the late Capt. Tanner. The abdominal cavity was full of blood. The perirenal tissues were much infiltrated and thickened. On the posterior surface of the kidney was an oblique track extending from the posterior border upwards and inwards, grooving the surface, as far as the upper pole. The missile was found between the kidney and the suprarenal capsule (see *Fig.* 195). The perirenal thickening involved the tail of the pancreas, and it was from this region that the hæmorrhage took place. The spleen was quite normal. The appearance of the kidney, and the results of the microscopical examination of sections from different parts and from the opposite kidney have already been described (see section on EFFECTS OF MISSILE ON KIDNEY).

Case 15.—Pte. T., under the care of Capt. Morgan. Shell wound. Wounded May 28, 1916. Capt. Meyer saw this case at a casualty clearing station. The wound was on the right side, and involved the ascending colon. Operation, May 29: A large hæmatoma on the outer side of colon. Much blood-clot removed from here. Laparotomy in middle line by Capt. Meyer, who found a hole in the colon and sutured it. Drainage anteriorly and posteriorly. May 31, fæces and urine began to escape from posterior wound. On June 8, a secondary hæmorrhage. Blood flowed from loin and into bladder. Patient was pulseless. June 9, pulse improved, rate 130. June 13, another hæmorrhage from loin and into bladder. Patient now absolutely pulseless. June 14, pulse again improved. June 16, fæcal fistula was closed. No hæmaturia now. Loin wound was opened and pus evacuated. Improved since. Evacuated to base. On June 27, another secondary hæmorrhage, filling up bladder. Severe suprapubic pain. A further hæmorrhage on June 28. On June 29, wound in loin extended and kidney explored. Laceration in lower pole, extending into pelvis. Some extravasation of blood in perirenal tissues. Sharp triangular piece of metal removed from just behind kidney. Kidney was removed.

Track of Wound.—From before back, towards loin, involving colon and kidney in transit.

Blood evacuated from bladder by catheter. Organisms in great numbers were subsequently found in urine, coliform, streptococcal, and diphtheroid. July 1, some cystitis. No blood. Improving. Patient made a good recovery.

Case 16.—Driver B. P., under the care of Capt. Thomas, at a casualty clearing station. Bullet wound. Injured June 5, 1916. Entrance wound right side at costal margin, 9·2 cm. from middle line in front. Exit wound, 7 cm. from middle line behind and 8½ cm. above highest point of iliac crest. Catheter required same night. Hæmaturia for six days. Catheter required for two days. No evidence of intestinal injury and no external bleeding. Temperature reached 100° at night for a few nights.

Track of Bullet.—Anterior abdominal wall, peritoneal cavity, liver, kidney, perirenal fat, and muscles of back.

On June 18 a small amount of blood again appeared in urine (twelve days after injury). June 19, no blood. June 26, a few pus cells in urine. Evacuated to England June 28, doing well. Only a few days at base.

Case 17.—Pte. S., under the care of Capt. Tobias. Shell wound. Hit June 11, 1916. Three wounds of back and some small wounds of upper arm. Admitted on June 12 to a casualty clearing station under Capt. Mann. Patient was pale, shocked, temperature 97°, pulse 108, respiration 40. Crepitus and dullness at base of left lung, dyspnœa, hæmoptysis, vomiting, hæmaturia, tenderness left hypochondrium.

June 14, urine clear. Admitted base hospital June 20. Urine then contained blood and pus. Temperature for a few days reached 102° in the evening, but gradually settled. Fracture of ninth rib on left side. Entrance wound on right side, size of a sixpenny piece, 12½ cm. above iliac crest, and 8½ cm. from mid-line. On left side, two superficial wounds. X rays show foreign body about 7 cm. to right of body of second lumbar vertebra and 4½ cm. from plate on back. No foreign body on left side where there are wounds. Cystoscoped, June 23: Ureters catheterized. Indigo-carmine injected into buttock. Both ureteral specimens show colour in ten minutes. The left (uninjured) side soon became more deeply stained. Both sides, sp. gr. 1015. There were a few red cells on the right (injured) side, but pus and micro-organisms were absent on both sides. On June 24, the piece of shell was removed from loin. It lay posterior to right kidney, the lower pole of which it had grooved to the depth of a quarter of an inch. There was much matting of perirenal fat. The injury to the lung on the left side was unconnected with the missile which injured the kidney on the right side.

Case 18.—Pte. B., under the care of Capt. Tobias. Shrapnel ball. Wounded, June 11, 1916. Multiple wounds. There was an entrance wound in left loin just above crest of ilium posteriorly. No exit. Retention of urine. Paraplegia. Complained of abdominal pain, which was relieved by catheterization. Hæmaturia. June 16, persistent vomiting. High swinging temperature. Vomiting continued, with abdominal pain, not localized. No tenderness or rigidity. Very slight dullness in right flank. June 20, vomiting and delirium until death.

Post-mortem.—Ball had passed obliquely upwards from the entrance wound, traversing third, second, and first lumbar vertebræ, passing through spinal canal, and wounding right kidney at upper pole. It had then passed into peritoneal cavity, and was found free in right iliac fossa. No other abdominal lesion. Recent secondary hæmorrhage from kidney. Subphrenic abscess. Cauda equina contused. No hole in theca.

Case 19.—Cpl. F., under the care of Capt. Ridewood. Rifle grenade. Wounded June 13, 1916, in back, thigh, and left hand. The wound in the back was on the right side. Hæmaturia for first time June 14. Urine clear to naked eye June 15. X rays showed shell fragments in right loin. There was a punctured wound 5·8 cm. above highest point of iliac crest and 10·4 cm. to right of centre of spine. Two fragments seen in skiagram. The smaller piece was 10·6 cm. deep from surface of back opposite lower part of body of first lumbar vertebra. The larger part was 9·7 cm. from surface of back opposite disc between first and second lumbar vertebræ. Both fragments were 5 cm. distant from right border of vertebræ. Cystoscopy, June 20: Bladder and ureteral orifices normal. Opaque catheter introduced into pelvis of kidney on right side. Radiography shows upper fragment 3·8 cm. anterior to catheter and lower fragment 2·2 cm. anterior to catheter. Both fragments are therefore probably anterior to kidney. The upper fragment ought to be in the liver, and the lower one in or touching the liver.

Track of Missiles.—Both probably took the following course: Erector spinæ quadratus lumborum, kidney, and peritoneal reflection between it and the liver.

Specimens of urine were taken from each ureter. Right side: sp. gr. 1015, blood-stained, no pus, epithelial cells from ureter. Left side: sp. gr. 1020, deep amber, no pus, a few red cells. Bacteria not seen in either specimen. Evacuated to England on June 22. The patient was recently heard of through the Medical Research Committee, and remains free from urinary symptoms.

Case 20.—Pte. A., under the care of Major West. Bullet. Hit in right loin. Laparotomy by Capt. Gross at a casualty clearing station. Large perirenal hæmatoma, and apparently perforation of right kidney by bullet. Wound closed, no abdominal viscera involved. The bullet had been previously removed by regimental surgeon. No history of hæmaturia. On June 20, 1916, a small abscess formed in the wound, and this was opened by Major West at a base hospital. June 26,

Capt. Henry found pus in small quantity, but no blood in urine. June 28, the wound again required opening up. Subsequent progress good. Notes of this case are incomplete.

Case 21.—Gnr. J. W., under the care of Capt. Whittington. Grenade wound of back. Wounded July 6, 1916. Passed urine containing blood two hours after injury. The cause of injury was a small fragment of metal, which was retained. There was rigidity and tenderness of right side of abdomen. No vomiting. Bowels opened with enemata. Urine contained blood until July 12, when it was found normal.

Case 22.—Pte. S., under the care of Capt. Bazett. Shell. Wounded July 16, 1916, in lateral aspect of right loin. Also a wound of right forearm. No history of hæmaturia. Missile retained in lumbar region. The day after admission to a base hospital, became suddenly blanched, and complained of great pain in right lumbar region, with rigidity. Pulse became very rapid. Operation, July 18: Transverse abdominal incision at level of umbilicus. Some blood-stained fluid in peritoneal cavity. Colon much ecchymosed. A large retroperitoneal hæmorrhage. Kidney explored. Found wounded, and removed. Clot cleared out. The kidney showed an entrance wound anteriorly in the lower third, and a larger wound on the posterior surface. There was much ecchymosis of the kidney. A patch of necrosis extended from entrance wound towards ureter. Patient died the same day.

Case 23.—Pte. A., under the care of Capt. Tobias. Shell. Wounded on July 14, 1916, in right side of back at level of crest of ilium, 2 inches from mid-line. Missile retained. *X* rays show missile opposite second lumbar vertebra about 3 inches from mid-line, and 3¼ inches from plate on back. Urine contains red blood cells, pus cells, and granular casts. No previous kidney trouble. On July 18, had two rigors, temperature rising to 101° in one and 104·8° in the other. The fragment was located just below the last rib near its outer part. There was an irregular shadow of doubtful nature in the neighbourhood of the ureter, opposite the third lumbar vertebra on same side. Operation, July 19: Exploration of kidney. Normal kidney found. Missile had passed through crest of ilium, across line of ureter, leaving on its way a wad of clothing. This may have been the source of the irregular shadow. The track passed on in front of the lower pole of the kidney through an aperture in the peritoneum, and was not further followed. It was thought that the condition of the urine might have been due to contusion of the ureter or kidney. There was some ecchymosis in the track, but the kidney was not obviously affected.

Case 24.—Pte. W. E. E., under the care of Major McEwen. Shell. Wounded in back, left side, July 21, 1916. Fragment entered between eleventh and twelfth ribs in posterior axillary line, and probably involved the lower part of diaphragm. An hour after being hit he noticed blood in his urine. Admitted to base hospital on July 23. July 24, urine still coloured, but no pus in it. Gas infection in and around wound. July 26, Major McEwen removed a piece of shell with clothing from the depths of the wound, slightly anterior to the lower pole of kidney. There was a good deal of oozing after the operation. Urine escaped from wound in loin. July 27, severe secondary hæmorrhage into bladder. Wound rapidly opened up and pedicle clamped. Later in the day, nephrectomy. Death, nine hours later. Kidney was enlarged. A large ragged wound was found extending into the pelvis. Area around the wound ecchymosed. Cortex pale and stippled with dark dots. Pyramids pale-red in colour. The kidney shows disorganization around the ragged wound, and an area of necrosis near cortex. For microscopical examination see under EFFECTS OF MISSILE ON KIDNEY.

Case 25.—Lieut. S., under the care of Major Martin. Bullet. Wounded July 23, 1916, through right loin. Same day passed blood in urine. Entrance wound, mid-lateral line, 4 inches above iliac crest in tenth intercostal space on right side. Exit wound, on same level half an inch to left of spinous process of second lumbar vertebra.

Probable Course of Bullet.—Chest wall, lower part of pleural cavity, peritoneal cavity, liver, lower half of right kidney, across back to emerge on left side, possibly damaging bone of lumbar spinal canal in its passage across the middle line. No spinal symptoms.

Admitted Guy's Hospital, London, on July 29. There was a note from this hospital to say that "the entrance wound was healed, but the exit wound was septic." On evacuation to England he still had blood in his urine. On Aug. 6, about a fortnight after his injury, hæmaturia was noticed. Aug. 21, very profuse hæmaturia; about a pint and a half of pure blood was passed. After each attack the urine gradually became free from blood. At no time were pus cells found. Aug. 26, very profuse hæmaturia. This continued until his kidney was removed on Aug. 29. Recovery uneventful.

I am indebted to Mr. C. H. Fagge, of Guy's Hospital, for the following note: "Lieut. S. had several hæmorrhages, and I operated for progressive anæmia, rising pulse, and pain so severe that he said that he could not stand it any longer. The kidney is in Guy's Hospital Museum. The depressed area (just below the middle of the organ and at its outer border) was quite yellow, and looked like an infarct; there was a tear above the yellow area, and some blood and pus around the kidney, but it was evidently a mild infection. There was no wound of the pelvis."

Case 26.—Pte. H., under the care of Lieut.-Col. Upjohn. Shell wound over left erector spinæ opposite second lumbar vertebra. A large incision had been made in erector spinæ at a casualty clearing station. Admitted to base hospital, Sept. 22, 1916. *X* rays showed a large piece of shell, deeply situated, probably involving the upper half of left kidney. Microscopical examination of the urine showed red and white blood cells. There was much albumin present. The temperature ranged from 100° to 103°, and the pulse was rapid. On Oct. 11 nephrectomy was decided on. There was free venous bleeding, and Col. Upjohn found it impossible to deliver a large soft friable kidney through the loin with safety. There were firm adhesions of the capsule to the perinephric tissues, and in trying to remove the kidney after decapsulation, it was found divided into an upper free third and a lower, less free, two-thirds. The foreign body was found and removed, and the kidney left in position. The patient died on Oct. 13.

Post-mortem.—A small amount of turbid fluid was found in the left kidney peritoneal pouch, but no definite peritonitis. Both kidneys were about twice the normal size, soft, dark in colour, with lighter greyish streaks on section. No areas of distinct suppuration found. The capsule of the right kidney peeled in a normal fashion. The left perinephric tissues were infiltrated with blood, and were thickened and sodden with inflammation. The left detached renal capsule was similarly greatly thickened. The pancreas had been cut across by the shell fragment, and the splenic vein was torn, but the splenic artery was intact. The distal end of the pancreas was black, but still firm. [There is no note of fat necrosis.—A. F.] The kidney was seen to be completely separated into two parts, an upper third supplied by an aberrant artery, and a lower two-thirds receiving the main vessels. The torn surface was greyish, but sections of the kidney substance showed it to be of a dark maroon colour, with the greyish streaks before referred to.

I am indebted to Lieut.-Col. Upjohn for the notes of this case.

Case 27.—Pte. G. S., under the care of Capt. Kelly. Shell. Wounded Oct. 10, 1916. Entrance wound one inch to left of eleventh dorsal spine. No exit wound. No paraplegia. Chest: nil. Abdomen: tenderness in left hypochondrium and left lumbar region. *X* rays showed no foreign body. No blood in urine. Oct. 13, abdomen very distended; vomiting; tenderness and rigidity in left lumbar region. Operation at a casualty clearing station: entrance wound excised. Track could not be followed by finger. Abdomen opened through outer edge of left rectus. No free fluid. No injury to intestine. Large retroperitoneal hæmatoma. Abdomen closed. Hæmatoma drained extraperitoneally through an incision in loin. Oct. 17, urinary fistula (a week after injury). Urine flowed from this, but no blood. Oct. 27, two moderate hæmorrhages from lumbar wound. Admitted to base hospital, Oct. 30.

Patient anæmic and wasted. Moderate fever. Pulse raised. Much urine coming from a deep wound in loin. *X* rays failed to discover any foreign body. (This may have been removed at casualty clearing station.) Tubular breathing and a little dullness at base of left lung. Cystoscopy, Nov. 2: Both ureteral orifices normal, both exhibit systole and diastole. No fluid from left; clear urine from right. Catheter on left arrested 6 inches from mouth of ureter. Collargol solution injected (see *Fig.* 199). Skiagram now taken. Fluid had evidently escaped into surrounding tissues from a hole in ureter. Some, however, had reached the pelvis, and distended it and the calices. The urine from the bladder and the right ureter contained some epithelial cells, a few pus cells, and a trace of albumin. Patient was evacuated to England on Dec. 3, with his wound dry. No urine had passed by the wound for three days. The missile here had probably passed down obliquely, injuring the lower part of the pleural cavity, the retroperitoneal tissues behind the kidney, and the ureter.

Case 28.—Pte. W., under the care of Capt. Tobias. Shell. Wounded Oct. 16, 1916. Entrance, tenth chondro-costal joint, right side: exit, behind, at a slightly lower level, 2½ inches to right of mid-line. No pain in abdomen, but burning pain in back of thigh. Blood in urine. No abdominal tenderness or rigidity. Operation at casualty clearing station by Major Gardner: abdomen opened. Colon uninjured. Foreign body had passed through chest wall, driving a portion of rib into liver. The damaged portion of rib was removed. It was found that there was a groove in outer border of right kidney. The laceration of the liver bled moderately. There was vomiting, with rapid pulse, during the night of Oct. 18, and bile and blood issued from the posterior wound. Patient improved, and was sent to base. Arrived at base hospital on Oct. 29, doing well. Capt. Henry reported much blood and pus in urine. Evacuated to England Nov. 4.

Case 29.—Pte. A. C., under the care of Capt. Kelly. Shell. Wounded Oct. 25, 1916. Entrance wound, left side, just below last rib. No note of blood in urine, Laparotomy by Capt. Rollinson Oct. 28. A little blood in peritoneal cavity. Retroperitoneal hæmatoma. Lower pole of left kidney lacerated. This was packed and drained. Missile not found. Admitted to base hospital, Nov. 6. Wounds clean. Abdominal wound had healed per primam. No blood in urine. Foreign body removed from a swelling over crest of ilium. Urine was examined by Capt. Henry on Nov. 10. It contained a trace of albumin, a few pus cells, and red blood-corpuscles. Evacuated to England, Nov. 15, much improved.

Case 30.—Pte. G. W., under the care of Major West. Shell. Wounded Nov. 13, 1916. Wounds of right foot, and right side of chest. Fractured tibia. A small hæmothorax. Nov. 19, amputation of leg. Nov. 23, some oozing from stump. Nov. 25, passed almost pure blood per urethram. This was the first indication that any injury had been done to urinary organs. *X* rays showed a fragment of shell 2 inches from central line on right side, just external to tip of transverse process of third lumbar vertebra. It was located as being, probably, in the psoas muscle. The entrance wound was in the chest wall, fifth interspace on right side, two fingerbreadths outside nipple line.

Probable Course of Missile.—Chest wall, lung, pleura, diaphragm, liver, lower pole of kidney.

The secondary hæmorrhage occurred twelve days after injury. Cystoscopy, Nov. 25. Left ureteral orifice normal and discharging clear urine; right shows a long rope of blood-clot attached to orifice; bladder normal. Urine from left side normal; the few drops obtained from the injured side contained blood but no pus. Operation, same day: kidney removed. The organ was pale in colour (see *Figs.* 191, 192). There was an entrance wound at lower pole about an inch long, surrounded by an irregular ridge. There was a small exit wound on posterior surface. The wound on anterior surface was surrounded in the fresh specimen by a yellowish-white slightly raised area, and there was a similar wedge-shaped area occupying the anterior surface, posterior border, and posterior surface at lower pole. This is well depicted in the drawing by Sergt. Maxwell. The shell fragment was removed from

the spot indicated in the radiogram. The large clots of blood which had accumulated in the bladder were washed out with an evacuator. Cystitis developed after operation. Recovery.

Case 31.—Sergt. D., under the care of Capt. Morgan. Shell. Wounded Nov. 11, 1916. Entrance wound at level of lower border of second lumbar vertebra and 2 inches from mid-line on left side behind. Paraplegia. Admitted base hospital Nov. 19. Nov. 20, abdominal distention was noticed, and very profuse hæmaturia, with vomiting. X rays showed a large piece of metal at level of twelfth dorsal vertebra on right side, 3 inches from mid-line and 4¾ inches deep from back. Two days after admission, had rigors, temperature running up to 106°. Nov. 25, blood was still present in the urine. Nov. 26, blood had entirely disappeared, even on microscopical examination.

Track of Missile.—Reconstructed as follows: Skin, transverse process of second lumbar vertebra, cauda equina, body of first and disc between first and second lumbar vertebræ, psoas muscle, right kidney, liver (in which progress of foreign body was arrested). The patient died on Nov. 26.

Post-mortem.—The missile was found to have traversed the body of the second lumbar vertebra, then a vessel passing to the lower pole of the kidney, finally coming to rest in the liver. Hepatic abscess. The right lung was adherent to the diaphragm, and the latter to the kidney. The coloured drawing by Sergt. Maxwell (see *Fig.* 194) is a faithful representation of the appearances seen. The necrosis of the area supplied by the wounded vessel is well depicted, and some of the infiltrated perirenal tissue is shown.

Case 32.—Pte. G., under the care of Capt. Edwards, to whom I am indebted for short notes of this case. Shell. The patient was wounded on Nov. 25, 1916, by a piece of shell which was retained. Hæmaturia was present. On Dec. 24 severe secondary hæmorrhage took place via the external wound. The patient was blanched. Affected kidney removed on Dec. 25, and blood transfusion performed immediately after. The improvement in patient's condition was dramatic and he made a satisfactory recovery. There was a small perforating wound of the kidney near the centre, with an area of necrosis around the points of entrance and exit. For microscopical examination of removed kidney, see section on EFFECTS OF MISSILE ON THE KIDNEY.

Case 33.—Gnr. J., under the care of Capt. Hemmans. Shell. Wounded Dec. 28, 1916. Laparotomy at casualty clearing station, No injury to gut. Spleen intact. Large retroperitoneal hæmatoma. There was a wound in loin. This was opened up, and foreign body was felt in substance of the kidney, but could not be removed with safety. There was a tear in substance of kidney, which was plugged. Lieut. Donaldson, at clearing station, with stereoscopic radiography, located a foreign body lying 8 cm. below skin-mark. The foreign body moved with respiration. When admitted to base hospital, the urine contained a little blood, and urine was leaking from a wound in the loin. The patient was very anæmic, and had been running a temperature up to 104° and a pulse of 120 or so. There had been a good deal of sepsis in the loin, and several incisions for cellulitis had been made. Capt. Gamlen *x*-rayed the patient, but failed to find any foreign body. This may have escaped unnoticed, or may have made its way into a hollow viscus. On Jan. 21, 1917, there was no blood but some pus in urine. Jan. 31, his wounds were almost healed, and there was no leak of urine. He was evacuated to England on Feb. 1. His urine was then free from blood, pus, and albumin.

Case 34.—Pte. W. M., under the care of Capt. Morgan. Shell. Wounded March 4, 1917. Multiple wounds. The wound in right lumbar region was 12 cm. from mid-line behind and 7 cm. above iliac crest, about the eleventh intercostal space. About an hour after being hit, he passed urine stained with blood. When seen at a base hospital, on March 7, abdomen was somewhat rigid, he was vomiting, his urine was dark in colour, tongue brown, pulse 108, temperature 101°. The urine contained

much blood, a very few pus cells, and a heavy deposit of urates. Icteric tinge in conjunctivæ. Slight cough. *X* rays showed a fragment of metal, 7·6 cm. deep from back, 10·6 cm. from mid-line, at level of lower border of twelfth dorsal vertebra. There was also another small piece of metal, probably in muscles of back.

Track of Missile.—Reconstruction shows that it probably grooved the outer border of right kidney and came to rest in the liver.

On March 27, urine only contained a few red cells, a few pus cells, and no bile. Cystoscopic examination discovered very little difference between the specimens drawn from each kidney. Indigo-carmine was delayed on the affected side, taking twenty-five minutes as against twenty on the undamaged side, under an anæsthetic. The specific gravity was equal on the two sides.

Case 35.—Pte. J. S., under the care of Capt. Palmer. Shell. Wounded, March 12, 1917. Small punctured wound $1\frac{1}{2}$ inches above left iliac crest and $1\frac{1}{2}$ inches to left of mid-line. Abdomen was found rigid when admitted to casualty clearing station same day. On March 15, when admitted to base hospital, no abdominal symptoms. Straw-coloured fluid (urine ?) was discharged in small quantity from wound in the loin. *X* rays showed three foreign bodies in the loin. The largest was located just above and in front of the transverse process of the second lumbar vertebra. The other two fragments were minute. Urine examined on several occasions. On March 17, it was reported free from albumin and blood. March 20, a trace of albumin and blood, pus corpuscles in fair quantity, and one or two broken-down granular casts were found. March 23, urine normal. March 27, albumin and blood present. A couple of rises of temperature to 101°–102°. Cystoscopy, March 29. Bladder and ureteral orifices normal. Indigo-carmine came through ten minutes after injection, but was slightly more marked in urine on affected side. Sp. gr. of both specimens, 1020. A few red cells and a trace of albumin on each side. Opaque ureteral catheter was introduced to locate position of foreign bodies relative to kidney. The largest was 4 cm. behind the catheter, and one of the smaller ones was 1·9 behind the catheter. It is probable that the kidney was contused, but not otherwise injured.

Case 36.—Pte. S. B., under the care of Lieut.-Col. Gordon Shaw, to whom I am indebted for the notes of the earlier progress of the case. Revolver bullet. Admitted to casualty clearing station March 11, 1917, four hours after being wounded. Small punctured entrance wound in back at level of third lumbar vertebra, 2 in. to right of mid-line. No exit. Tenderness and rigidity on right side of abdomen. Right flank dull on percussion. Right side of chest dull to level of eighth rib in line of angle of scapula. Patient passed some deeply blood-stained urine. No vomiting. Pulse 104, temperature 101°, respirations 44. Breathing not distressed. Laparotomy, same day: free blood and blood-clot in peritoneal cavity. A punctured wound was found on the anterior surface of the kidney, just to right of second part of duodenum. An entrance wound in liver immediately in front of transverse fissure, and an exit wound was felt in the dome of the liver. Some extravasation of blood behind second part of duodenum. Col. Shaw divided the peritoneum on the outer side of the duodenum, mobilized the latter, and drew it over to left. Wound about $1\frac{1}{4}$ in. in length discovered on posterior and outer surface of duodenum, extending down to, but not through, the mucous membrane. This was repaired, the duodenum was restored to its position, and the peritoneum sutured. Drainage tube through right flank by stab puncture. Abdomen closed. Next day, double lobar pneumonia. March 13, leakage of urine from loin. March 25, right pleural cavity explored with needle, and sterile blood-stained fluid drawn off. On April 2, urinary fistula practically closed. After his arrival at the base, an empyema on right side was drained by Lieut.-Col. Taylor. On May 27. urine was free from albumin, pus, and blood. Cystoscoped, June 4, about three months after injury: both kidneys secreting well. Sp. gr. on both sides, 1010. Indigo-carmine came through in fourteen minutes on both sides.

Case 37.—Driver R. T. W., under the care of Major West. Shell. Wounded April 3, 1917, in back. Paraplegia. Blood in urine on first catheterization at casualty

clearing station. Entrance wound, half an inch in diameter, 11 cm. to left of spine and just below last rib. Admitted to base hospital, April 6. X rays show a large fragment of shell between second and third lumbar vertebræ. Operation, April 8. Laminectomy. Fragment easily found behind cauda equina, which was exposed. Wound was investigated, and found to travel upwards and inwards, with a pocket towards renal region, but no connection with kidney was seen. The latter was therefore probably contused by transference of impetus of missile during passage. Evacuated to England.

Case 38.—L.-Cpl. J., under the care of Capt. Hannigan. Shell. Wounded in left loin, April 9, 1917. Urine removed by catheter, thirty-three hours after injury, contained blood. No vomiting. General condition good. Entrance wound about 1 cm. above iliac crest, left side, and 5 cm. behind line of anterior superior iliac spine. No exit. Admitted base hospital April 11. Still requires catheter. Pulse 92; temperature 100°–102°. Lower quadrant of left side of abdomen dull, tender, and rigid. X rays: nil. Slight fever. April 14, pulse and temperature now normal, dullness in flank disappearing: still requires catheter. April 15, urine almost clear. Patient was evacuated to England a few days later, still requiring catheter.

Case 39.—L.Cpl. K., under the care of Major McEwen. Shrapnel ball. Hit April 9, 1917. Multiple wounds. Two in back. One entrance wound in left lumbar region just below ribs and about two inches from spine. Exit over lower ribs, two finger-breadths from costal margin in nipple line. Passed blood in urine day after injury. Some abdominal pain in hypogastric region. Few signs, if any, in renal region.

Reconstructed Track of Missile.—Left kidney, abdominal cavity in region of jejunum and stomach, just outside left edge of liver.

April 26, still passing blood. April 28, blood had disappeared, but a little pus and some albumin were found. A shrapnel ball (one of several that had injured him) was removed from scrotum. Cystoscoped, April 30: ureteric orifice on affected side (left) slightly puffy. Indigo-carmine came through on both sides in eighteen minutes under ether anæsthesia. The colour was, however, deeper on affected side. Specimen from right side: acid, sp. gr. 1010, trace of albumin, no pus, a few epithelial cells, a few streptococci. Left (affected) side: acid, sp. gr. 1005, cloudy, albumin, pus, streptococci a small bacillus like *B. influenzæ*, and a coli-like bacillus.

There was apparently a slightly diminished flow on affected side. Note that the specific gravity was lower on affected side, but the colour of indigo-carmine was deeper.

Case 40.—Pte. P., under the care of Capt. Swan. Shell. Wounded, April 7, 1917, on left side. An hour later, passed urine mixed with blood. Vomited once, On admission to base hospital, entrance wound between eleventh and twelfth ribs, 8 cm. from mid-line, left side. No exit. X rays show large piece of metal lying deep to twelfth rib, 6·3 cm. from back and 7·4 cm. from left side of body of first lumbar vertebra. The fragment was 1½ cm. in length. Twelfth rib fractured about middle. Patient has had pain for four or five days in left hypochondrium. On April 17, urine was quite clear. Foreign body judged to be in left kidney. An opaque catheter would have been valuable here, but stress of work in the hospital did not permit. Probably the lower part of pleural cavity and the diaphragm were involved. Very little rigidity or tenderness in abdomen. Pain on coughing. April 18, report on urine: no blood cells, a very few pus cells, and some bladder epithelium. Evacuated to England.

Case 41.—Pte. T. W. E., under the care of Major West. Shell. Wounded April 24, 1917. Wound left side, back of loin. Arrived at base, May 6. May 7, a secondary hæmorrhage from wound, which ceased. Repeated on May 8. Operation, May 8. The eleventh and twelfth ribs were broken, but pleural cavity apparently not opened. (No chest signs had been present.) There was a colostomy opening discharging fæces into wound. Lower pole of spleen lacerated and sloughy. Bleeding was seen to

come from the kidney, the lower pole of which had stitches in it. Kidney removed. Before operation, clear urine was drawn from the bladder. The notes of this patient were lost in transit between the clearing station and the base. The patient died three days later from sepsis. The injury to the kidney was confined to the lower pole, which was foul and sloughy.

Case 42.—Sergt. H. F. L., under the care of Major West. Shell. Hit Jan. 2, 1917. Entrance wound, left side, posterior axillary line. Exit, right side, mid-axillary line, just above crest of ilium. Abdomen soft. Hæmaturia. Paraplegia. Pulse had varied from 100 to 120 during first twenty-four hours. Later, came down to between 92 and 100. Catheterized every six hours. Some urethritis. Cystitis. Jan. 8, *x* rays showed fracture of body of first lumbar vertebra. Blood present in urine, an ounce or two of blood-clot in each pint. A second skiagram showed a piece of metal on left side, 2½ inches from mid-line, below twelfth rib, probably in kidney. On right side another piece, deep in muscles. Also fracture of second lumbar vertebra at junction of pedicle and lamina on left side. Pieces of loose bone. In region of left kidney, a deep swelling. Dullness over left lower ribs below axilla. Jan. 13, much vomiting for the last few days. Died, Jan. 15.

Post-mortem made by Capt. Henry.—Lower half of first lumbar vertebra and upper half of second lumbar vertebra in region of transverse processes and laminæ have been smashed by missile, which has passed obliquely through the bony canal from side to side, tearing dura mater, through which cauda equina is prolapsed. Large suppurating hæmatoma around left kidney. Extensive laceration of middle of outer border of left kidney. (See *Fig.* 193.)

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ILLUSTRATIONS OF WAR SURGERY.

(*Continued from Vol.* iv, *page* 63.)

[Under this heading we propose to publish during the War a series of drawings illustrative of military surgery in its various aspects. The BRITISH JOURNAL OF SURGERY is indebted to Surg.-Gen. Sir George H. Makins and Surg.-Gen. Sir Anthony Bowlby for their help in the selection of cases and for their clinical remarks on certain of those selected. The notes, supplied by various officers of the Royal Army Medical Corps, under great pressure of work, are necessarily brief. The drawings have been made by artists specially commissioned for the purpose.]

Bullet Marks upon the Skin of the Abdominal Wall: with a Note on the question of the Heat retained by the Spent Bullet. (BY SURG.-GEN. SIR GEORGE H. MAKINS and LIEUT.-COL. PINCHES.)

The drawing, *Fig.* 200, represents appearances seen on the abdominal wall of the umbilical region of a man under the care of Lieut. Fergusson.

FIG. 200.

The history of the case was as follows: Three days before admission the patient received two shrapnel-case wounds, one in the buttock, the second in the leg, neither of them being severe.

He fell on his back into a ditch, and while lying there "felt a sharp burning pain over the abdomen: he drew up his shirt and removed a bullet from between it and the skin. The bullet was not hot when he touched it."

When seen on the third day, five apparent impressions of the bullet were discovered, rosy-red in colour. At the upper end of the broad one a scab following the drying up of a vesicle was seen, while at the tip of the innermost of the three lower impressions a vesicle containing serum was still present.

The drawing has been made from a sketch depicting the exact size of the 'burns,' taken at the time by Lieutenant-Colonel Pinches, who was then acting as my A.D.C.

The illustration bears upon the vexed question as to the temperature of a recently-fired bullet. I have occasionally seen red marks suggesting the outline of a bullet upon the body, but have never met with a case in which such circumstantial evidence was offered. Naturally, the retention of a spent bullet between the skin and the patient's clothing is a rare occurrence, while if such bullets are met with, it is usually only after they have undergone the cooling process of passing through the body.

The evidence must be accepted or rejected by individual judgement, the appearances presented were in my own opinion those of a burn, and I see no reason to disbelieve the history of its occurrence given by the patient. [*Ref. No.* 199.]

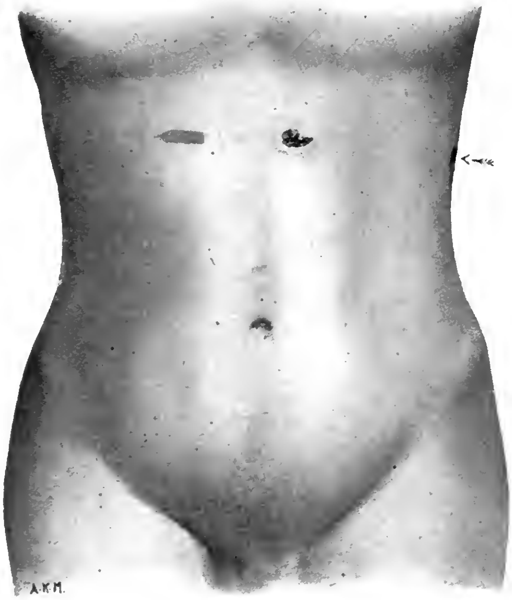

Fig. 201.

Fig. 201.—Represents a similar case, except that in this instance the bullet had traversed the tissues. This patient also was under the care of Lieutenant-Colonel Pinches, who has kindly given the particulars. The bullet entered in the eighth intercostal space of the left side in the anterior axillary line, and emerged in the epigastrium. The patient felt something burning him, and got up from the ground; he put his hand under his shirt and removed a bullet from above the pubes. In this instance also the outline of the red mark closely corresponds to that of the bullet, and it is difficult to believe that it does not correspond with the primary position taken up by the spent bullet. [*Ref. No.* 200.]

Bomb Wound of Face.

The drawing, *Fig.* 202, illustrates an extreme instance of 'fine tattoo' of the skin of the face surrounding a wound leading down to a fracture of the mandible. The patient was under the care of Dr. Kazanjian, in the 'oral'

Fig. 202.

department, where the fracture of the jaw was being treated. This beautiful drawing of Mr. Maxwell's, taken with those published in foregoing numbers of The Journal of Surgery, may be said to complete the depiction of the varying degrees of minor injuries to the face resulting from bomb wounds.*

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* Vol. iii. *Fig.* 37, p. 114: "A patch of small areas gives the appearance of a coarse 'tattoo.'" *Fig.* 85, p. 267: Multiple shell wounds. *Fig.* 167, p. 503: Bomb wound of face.

A CONTRIBUTION TO THE PATHOLOGY OF PROJECTILE FRACTURE OF LIMB BONES.

By Major E. K. MARTIN, R.A.M.C., and Captain G. F. PETRIE, R.A.M.C.

Projectile fractures observed during this war have created new problems, owing partly to the frequent complexity of the lesions, and partly to the co-incident infection, of a type rarely encountered under civil conditions. They have given far greater opportunities than have occurred hitherto for the study of the interaction of bacteria and bone. It is the purpose of this communication to illustrate these reactions as they occur during the first six weeks after infliction of the wound, and to show that they may be modified not merely by morbid changes incidental to the local trauma, but by circumstances remote from and independent of the primary injury to the bone. These conditions, whether local or remote, and whether acting singly or in combination, tend to produce a variety of types of infection, ranging from the unrestrained bacterial invasion of a damaged bone, to the deviations from this type brought about by surgical intervention. In the absence of clear conceptions of the progressive changes within the bone which lead either to healing or to a state necessitating radical surgical interference, the foundations of rational treatment do not exist.

The material on which this paper is based was derived from thirty-two patients at a base hospital in France, and comprises a variety of infected fractures, chiefly of the cancellous tissue, but also of the shaft, of long bones. The cases were taken at random as opportunity offered, and of necessity include a considerable proportion which were not on the road to recovery. In addition to clinical observation of each case, the fracture and adjacent soft parts were dissected, and bacteriological examinations were made from serial sections of the bone. The results have shown that the variables contributing to form each type of infected fracture are such as to make it desirable to accumulate for examination a sufficient number of examples to allow of a grouping of the cases for statistical analysis. The importance of this lies not only in confirming isolated or limited findings, but in tracing the stages through which infection of bone passes, and in attempting to correlate clinical states with the nature and degree of the infection. Although the observations recorded here do not altogether reach this standard, they have indicated certain lines along which the problem may be attacked, and have led to a number of reasonably definite conclusions.

The scope of the inquiry is indicated in the following scheme :—

I. Mechanical Accompaniments of Projectile Fracture.
  Bruise.
  Fissure.

I. MECHANICAL ACCOMPANIMENTS OF PROJECTILE FRACTURE.

The varieties of projectile fracture are so well known that formal description of them is superfluous. Two features, however, stand out so prominently as to repay detailed examination—namely, the bruise which invariably accompanies gunshot injury of bone, and the fissures which commonly do so.

Bruise of Cancellous Bone.—When a missile strikes cancellous bone, a bruise is produced at the point of impact, whether the outer compact layer is broken or remains intact. Bruising is met with under three conditions : (1) Direct bruise round the track of a penetrating missile ; (2) Direct bruise without penetration ; (3) Indirect or contrecoup bruise in the same or an adjacent bone.

1. *Direct Bruising round a Missile.*—Examples are shown in *Figs.* 203, 204, and 205. In *Fig.* 203, the periosteum has been removed from the back of the tibia to show the bluish appearance of the bruise as seen through compact bone. The articular cartilage is stained by the blood in the joint except at the site of the bruise. In the transverse section of the same tibia, taken immediately below the embedded shrapnel ball, the characteristics of a typical bruise are seen—the dark-red colour of the effused blood filling the cancellous spaces, the outline concentric with the foreign body, and the sharp line of demarcation, broken only by a slight tendency to radiation at the junction with the normal bone. This bruise was sterile on culture, and the whole specimen demonstrates the type colours of a recent aseptic trauma.

Fig. 205 represents a horizontal transverse section of one femoral condyle from a resection of the knee-joint for multiple shell-wounds. The joint contained a sterile blood-effusion. The figure shows clearly the sharp limitation of the bruise concentric with the shell fragment, and the characteristic absence of fissures radiating from the shell site. Several such bruises have been examined under a dissecting microscope, and the absence of even the smallest cracks in the trabeculæ confirmed.

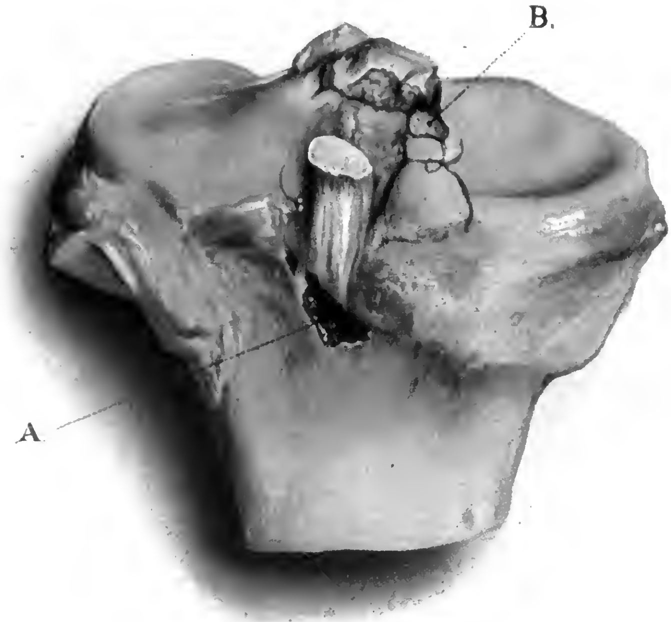


Fig. 203.—Upper end of tibia from behind, showing bluish appearance of bruised cancellous bone as seen on the surface after removal of periosteum. *A*, Entry wound. *B*, Shrapnel ball.

Fig. 204.—Transverse section of same tibia immediately below shrapnel ball, showing appearance of aseptic bruise two days after injury.

Figs. 206 and 207 show the extent of the bruising up the shaft from a penetrating wound of the femoral condyle accompanied by fissuring.

Fig. 208 (*Case* 12) shows a bruise which was produced by a minimal tangential blow. The articular cartilage was chipped, but the subjacent compact layer of bone was not even cracked.

The colour of a bruise fades rapidly on exposure to the air or immersion in water. During an operation, an underlying bruise is easily recognized by the bluish colour on the surface of the overlying bone or articular cartilage. When exposed, it is a much darker red than normal cancellous tissue.

2. *Direct Bruising without Penetration.*—Direct bruising of the condyles of the femur without fracture has been found associated with extensive flesh wounds where large shell-fragments of low velocity have opened the knee-joint and necessitated amputation for suppurative arthritis.

3. *Indirect or Contrecoup Bruising in the Same or an Adjacent Bone.*—*Fig.* 209 shows a direct and indirect bruise in the same bone. Z^1 is the direct bruise round the fracture, separated by a zone of undamaged bone from Z^2, the indirect bruise produced by impact of the head of the humerus against the scapula.

Fig. 211 shows the extent of an indirect bruise which was produced in an otherwise uninjured tibia as a contrecoup effect from a fracture of the lower end of the femur (*Fig.* 210). This bruise showed on the upper surface of the tibia as a bluish discoloration round the spine, but no crack of the latter or of the articular cartilage existed.

Fig. 205.—Section of femoral condyle with embedded shell-fragment, showing bruise without fissuring; day following injury.

Bruising of the marrow of the shaft similarly accompanies fracture. Owing to the thickness of the surrounding compact layer, it can only be seen on section. Where fissures exist, the bruising always extends up to, and may extend beyond, their limits.

Fissures.—These are found in both the compact bone of the shaft and the cancellous bone of the extremities, though much more commonly in the former. They can, in fact, be considered as a regular accompaniment of comminution, and frequently extend for long distances—10 cm. or more—up and down the shaft from the point of primary injury, or from the site of an embedded foreign body which has not produced a complete fracture.

Fissures are of two kinds—those which remain open, and those whose walls spring back into apposition as soon as the force of the blow is exhausted. The latter are found only in the elastic compact bone of the shaft, and unite

without incident, in contrast with the open fissures, which play an important part in spreading infection. They may be due either to the direct effect of the missile itself, in which case the fissure commences in the fracture and ends blindly in the bone, or to the indirect effect of the fall or muscle-twitch which follows the mechanical stimulus. In the latter case the fissure does not communicate at any point with the original bone wound, and is apt to assume the

Fig. 206.—Lower end of femur removed by amputation 48 hours after injury. Embedded shell-fragment, with surrounding fissures.

Fig. 207.—Longitudinal section of femur shown in *Fig.* 206. Extent of corresponding bruise.

spiral form associated with simple fracture; it is, in fact, a minor degree of the indirect complete fracture which not uncommonly accompanies direct partial fracture of another part of the bone, or occasionally may even be associated with a simple flesh wound of the limb.

All fissures in cancellous bone behave as open fissures. Apart from extreme comminution they do not often occur, unless prolonged from the

shaft, or unless a projecting portion of cancellous tissue is separated from the main bone by a perforating injury.

As a rule, a missile which penetrates the articular end of a bone, and remains embedded, cuts a tunnel but very little larger than itself, and comes to rest in a closely-fitting bed of bruised bone (*Fig.* 205). If a longitudinal section of such a tunnel is examined under a low power of a stereoscopic dissecting microscope after removal of the débris with which it is filled, the wall is seen to be sharply defined, the trabeculæ lining it being flattened by the pressure of the missile, while those in the immediate neighbourhood show no disturbance.

II. METHODS OF INVESTIGATION.

Nature of Material.—There are three sources from which material can be obtained: (1) Fragments of bone removed at operation; (2) Amputated limbs; (3) Autopsy.

1. Fragments of Bone Removed at Operation.—(*a*) *Small Fragments:* Cultures from bones were never made at operation, on account of the difficulty of carrying out an adequate bacteriological technique, and of the uncertainty of reaching the limits of infection in a living bone. (*b*) *Large Fragments:* The portions of bone removed in the resection of joints were found suitable for studying the spread of infection in cancellous tissue.

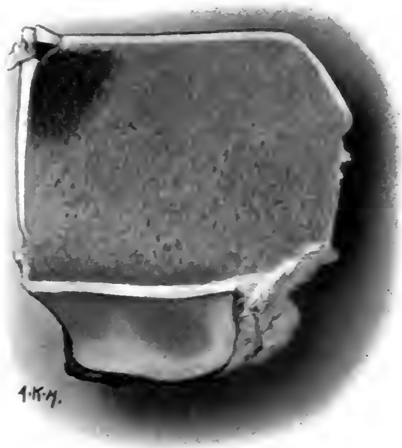


Fig 208.—*Case* 12. Coronal section of astragalus from amputation; 2½ days after injury. Bruise from minimal wound of articular cartilage without fracture of bone.

2. Amputated Limbs. — These were chosen as the principal source of material, for two reasons: (*a*) Because they are the most accessible source of fresh material; (*b*) Because it seemed probable that from them the processes at work in bones which ultimately unite might be reconstructed.

In order to obtain trustworthy data from the bacteriological examination of bones, it is essential that they should be examined immediately; or if this is impracticable, that steps should be taken to inhibit the growth of organisms which always follows the removal of any tissue from the body, and which makes it impossible to draw valid conclusions as to the conditions obtaining at the time of amputation. Post-mortem growth is illustrated by *Cases* 1, 2, and 3, Appendix I.*

3. Bones Removed at Autopsy.—In consequence of the liability to post-

* In order to avoid undue interruption of the narrative, detailed accounts of some of the cases have been collected in Appendix I, p. 328.

mortem growth, investigation of bone removed at autopsy has been confined to two cases in which no delay occurred in obtaining the material. Even if the material is taken immediately after death, the results do not necessarily correspond to those found in patients who ultimately recover; for where death is preceded by a gradual failure of the circulation, bacteria may grow as saprophytes throughout the bone during the terminal phase of the illness. In such a case the bacterial invasion is in reality a post-mortem phenomenon occurring during life (see *Cases* 4 and 5, Appendix I).

Details of Technique.

Procedure at Operation.—Under the anæsthetic a swab is taken from the wound as close to the fracture as possible; 10 c.c. of blood are withdrawn from a vein for cultural purposes; and if a joint is involved, a sample of the effusion is obtained by puncture away from the wound, after sterilization of the skin. The bone when removed is rapidly cleaned and put into ice, in which it remains until all preparations for investigation are complete.

Technique of Taking Bone Cultures.—After making a smear from the fracture, the whole bone is flamed with a blowpipe, and fixed in a vice which has previously been sterilized in the same way. Transverse sections are then made at measured intervals* with a flamed hack-saw, commencing at the end away from the fracture. The face of the section from which cultures are to be made is lightly seared, and pieces are scooped out with a *dry* sterile gouge. Before each successive transverse section, the bone and vice are lightly heated again with the blowpipe or searing iron.

FIG. 209.—Section of head of humerus removed by resection 5 days after injury. Z^1, Direct bruise extending from fracture. Z^2, Indirect bruise from shock against scapula.

Each of the fragments removed by the gouge is about the size of a pea. One is inoculated into a serum-broth tube, for aerobic cultivation; the other into a short, stout culture tube containing broth, fitted with a solid glass rod flattened at the lower end for the purpose of grinding up the bone fragment as far as possible; from this suspension anaerobic cultures are prepared, and the tube itself is also incubated as a control upon the aerobic cultures. Anaerobic cultures are made into tubes of broth and milk media covered with a layer of liquid paraffin. The broth tubes contain small pieces of coagulated

* Unless sections are taken at frequent and regular intervals throughout the bone, the limit of infection cannot be determined with accuracy. Experience has shown that an interval of 2 cm. is the most suitable.

white of egg to indicate the presence of proteolytic anaerobes. If marked proteolysis occurs, a subculture is made into the same egg-broth medium grown aerobically, to test whether the digestive action may not be due to facultative anaerobes. The flora of the aerobic and anaerobic cultures are compared by making fresh and stained preparations, and by plating on serum agar and MacConkey agar. The aerobic colonies are picked off and identified. Comparison of the aerobic and anaerobic growths makes it possible to determine the presence of strict anaerobes. Anaerobes, when present in the bone fragment implanted in the primary *aerobic* broth-culture, are frequently found to have grown freely, especially in mixed cultures, their growth being aided

Fig. 210.

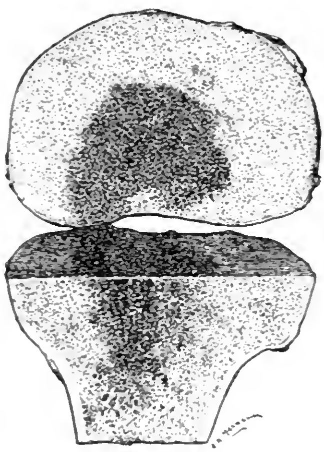


Fig. 211.

Fig. 210.—Shell fracture of lower end of femur.

Fig. 211.—Indirect or contrecoup bruise of upper end of tibia without fracture. Produced by blow on femur shown in *Fig.* 210. Sterile on culture.

by the layer of bone fat which forms on the surface. The complete identification of anaerobes was not undertaken, but the presence of *B. perfringens* was noted when the anaerobic milk-cultures presented the typical appearance of 'stormy fermentation'—that is, a clot of casein torn up by gas—and when, in such a culture, stout Gram-positive, non-motile, non-sporing, anaerobic bacilli were found.

Where necessary, smears of the bone samples are taken for microscopical examination.

There are two possible sources of error in the technique: (1) Overheating of the bone; (2) Contamination by bone dust from the saw.

1. To check overheating, a thermometer was placed in a tibia, and the bone flamed with considerably more vigour than that necessary to ensure

surface sterilization. The thermometer rose from 17·5° C. to 26·5° C. In practice there has been no reason to suspect any error from this source.

2. Contamination is guarded against by making transverse instead of longitudinal sections, by commencing at the end farthest from the wound and therefore the least heavily infected, by searing each surface immediately before taking the scoop, and by flaming bone and vice between successive sawings. In the earlier cases sterile liquid paraffin was allowed to drip on to the saw-blade; this had the effect of greatly diminishing the dust, and causing it to adhere to anything it touched, but was afterwards discarded as superfluous.

In spite of the refractory nature of the material examined, accidental contaminations were met with in only 6 per cent of the aerobic cultures. As a rule these could easily be recognized as such, and in practice did not hamper the deductions which could be drawn from the cultural results.

Controls.—Cultures were taken from the blood, and, where possible, from uninjured bone, for the reason that in an established streptococcal septicæmia the organism present in the blood can be recovered both from uninjured bone and from the damaged bone beyond the limits of local penetration.

The room in which the investigations were carried out was on a medical floor, and had never been used as a surgical ward; aerial contamination of the cultures by pyogenic organisms derived from septic wounds can therefore be excluded.

Recording of Results.—After taking samples for culture, each section of bone is put aside in order, and from these a diagram is reconstructed to scale later. It is important to preserve these sections for future reference, and to clean them thoroughly in order to trace minute fissures concealed by the periosteum and to obtain more precise measurements.

The following method has been found useful for rapidly cleaning sections of bone in order to study points of detail: Remove soft parts, and place in 50 per cent liquor sodæ chlorinatæ (B.P.) for twelve hours. Immerse in water at 80° C. for fifteen minutes. Replace in liquor sodæ chlorinatæ for two periods of half an hour each, with alternate washings in water at 80° C. Bleach in H_2O_2 for twenty-four to forty-eight hours. Immerse in rectified spirit, and dry.

Each transverse section is traced on a glass plate, from which the tracing is transferred to paper, and a note is made of the colour and appearance of the bone at the level of section. Bruising is indicated on the diagram by darker stippling. The levels of section are numbered in sequence away from the fracture for convenience of reference, although they are actually cut in the reverse order (see TECHNIQUE).

The direction, up or down, of each bacteriological sample is indicated on the diagram representing the whole bone, its size and position being defined by the tracing.

A centimetre scale is attached to the diagrams, but owing to an obliquity of some of the sections, which has not been reproduced, and to the difficulty of estimating the depth of each scoop, there is an occasional error of a fraction of a centimetre in the distance of a sample from the fracture. For the sake of uniformity this has been neglected, and measurements have been given to a millimetre in all cases.

The bacteriological findings are represented by the following conventional signs :—

Growth resulting from direct penetration of organisms from the fracture.

Growth of septicæmic origin.

Sterile.

Other conventional signs used are : A = Main fracture. A^1 = Fissure extending from main fracture. B = Foreign body.

For the permanent recording of colour, the most suitable medium is a good water-colour sketch. This must be made as quickly as possible, on account of the rapidity with which the colours of fresh bone change. The Kaiserling method, in our experience, has the limited advantage of differentiating bruised from normal bone, but has proved inadequate to preserve the natural colours. Klotz and Maclachlan's modification of the Jores method gives better results.*

III. SPREAD OF INFECTION FROM THE FRACTURE.

Within the time limits of this investigation—that is, the first six weeks after infliction of the wound—infection of bone is met with in two forms, penetration by organisms without suppuration, and spreading suppurative osteomyelitis. For this reason the term infection is used in this paper to imply the presence of bacteria in bone as demonstrated by culture, without reference to their fate or to the reactions they excite. Since pathological states intermediate between these two stages of infection have not been observed, we have employed the term penetration to signify a demonstrable progression of bacteria through bone away from a fracture. The term does not imply the co-existence of inflammation.

Penetration has proved to be the chief manifestation of infection in the material examined, to the extent that only one instance (*Case* 22) of spreading suppurative osteomyelitis has been met with out of 37 bones investigated. The rarity of suppurative osteomyelitis is due to the fact that the missile itself establishes some drainage of the bone simultaneously with the implantation of the infective agent—that is, the infection is from the first an open one, in contrast with the closed infection of osteomyelitis as met with in civil experience.

Varieties of Bacteria Isolated from Bone.—With few exceptions, the bacteria isolated from freshly examined material fall into four groups, streptococci, staphylococci, anaerobic bacteria, and coliform bacilli. The frequency of occurrence of these groups is shown in *Table* 1, in which also will be found data relating to the bacterial content of wounds and of joints during a comparable period of their surgical history. The figures for wounds have been reduced from data published by Captain A. Fleming ("On the Bacteriology of Septic Wounds," *Lancet*, September 18, 1915).

* Adami and Judah, *International Association of Medical Museums*, Bull. v, June 1, 1915.

Table 1.—Showing the Frequency of Occurrence of Bacterial Groups in Bones, Wounds, and Joints, expressed as Percentages (Actual Numbers in Brackets).

Infection	Bones	Wounds (*Fleming*)	Joints
Streptococcus..	33·6 (36)	35·4 (177)	55·5 (15)
Staphylococcus	23·3 (25)	15·0 (75)	25·8 (7)
Anaerobes ..	23·3 (25)	34·6 (173)	7·4 (2)
B. coli ..	19·6 (21)	14·8 (74)	11·1 (3)
Totals	100 (107)	100 (499)	100 (27)

Table 2.—Giving Details of the Source of Bacteria Isolated from the Material Analysed in *Table* 1.

Source	Streptococcus	Staphylococcus	Anaerobes	B. Coli
Femur ..	8 bones gave 15 cultures	4 bones gave 6 cultures	6 bones gave 12 cultures	5 bones gave 13 cultures
Tibia.. ..	5 bones gave 16 cultures	5 bones gave 8 cultures	5 bones gave 7 cultures	3 bones gave 4 cultures
Fibula ..	—	1 bone gave 1 culture	—	1 bone gave 1 culture
Os calcis ..	—	—	1 bone gave 2 cultures	—
Humerus ..	1 bone gave 2 cultures	3 bones gave 3 cultures	2 bones gave 2 cultures	1 bone gave 1 culture
Radius ..	—	2 bones gave 4 cultures	1 bone gave 1 culture	1 bone gave 1 culture
Ulna	1 bone gave 3 cultures	2 bones gave 3 cultures	1 bone gave 1 culture	1 bone gave 1 culture

Note on Tables 1 *and* 2.—The cultures from bones were derived from 59 samples taken from 29 bones (19 patients) giving a pure or mixed growth. The 29 bones examined were: femur, 10; tibia, 7; fibula, 2; os calcis, 1; humerus, 4; radius, 2; ulna, 3. The material was in every case removed at operation and examined fresh. and does not include specimens from cases of streptococcal septicæmia.

The results for joints include only those cases in which not more than two bacterial varieties were isolated, since mixed growths similar to those found in septic wounds are usually obtained from cases of extensive injury where the joint forms part of the primary wound, and where consequently there is no question of selection of the originally implanted bacteria.

Reviewing these results, it would seem that selection of the soil bacteria inoculated at the time of entrance of the missile takes place in the tissues, the process of selection affecting particularly the group of anaerobes. Thus, in wounds providing a nidus for growth of micro-organisms in muscle, anaerobes form a large proportion of the bacterial contribution, the proportion decreasing in bones, and still more so in joints. It may be that in the case of joints the suitability of the effusion as a culture medium is an additional factor determining the selection. These considerations are essential to the study of the sequence of infection in cases of fracture involving joints.

It has already been noted, and the point deserves emphasis, that in cases of streptococcal septicæmia, the streptococcus can be isolated from fractured bones beyond the limit of local penetration, and even from uninjured bones. A partial examination without a blood-culture control, made in ignorance of this fact, might easily lead to erroneous interpretations regarding the spread of infection. It is naturally difficult to decide whether the streptococcus in these cases merely resides in the blood-vessels of the bone marrow, or whether in addition some local multiplication in the perivascular tissue has taken place. The constancy with which positive cultures are obtained renders possible the latter supposition (see *Case* 13, and *Cases* 5, 15, 16, Appendix I). The results obtained in *Case* 15 suggest that, in spite of general septicæmic invasion of a bone, a progressive extension of streptococcal infection from the site of injury is demonstrable from the number of positive cultivations in a variety of media, dependent on the number of cocci present in the material implanted in the culture tubes. The culture results in this case are tabulated below.

Table 3.—*Case* 15 (*Fig.* 256).

Specimen taken for Culture	Situation relative to Fracture	Growth in		
		Aerobic Broth	Anaerobic Broth	Anaerobic Milk
Femur 1	Lower fragment : in fissured portion	+	+	+
,, 2	Lower fragment : at limit of fissure	+	+	+
,, 3	Lower fragment : 2·1 cm. beyond fissure	+	0	+
,, 4	Lower fragment : 7·8 cm. beyond fissure	+	0	0
,, 5	Upper fragment : 3·4 cm. from fracture	+	0	0

+ = Growth of streptococcus.

The *B. pyocyaneus* and *B. proteus* were not often encountered, the former having been found in only 3 samples out of 112 yielding cultures (2·6 per cent)—see *Case* 17 ; and the latter in 2 out of 112 samples (1·7 per cent)—see *Case* 14.

From two bones in which necrosed comminuted cancellous tissue was present on the surface of the fracture, a number of aerobic bacteria, probably associated with putrefaction, and giving unfamiliar reactions, were isolated. As this phase of infection is not typical of the series of cases investigated, an account of the bacteriological findings need not be given.*

Examples of Penetration through Normal Bone.—The simplest conditions under which penetration of bone can be studied are those obtaining at the end of an open amputation stump where the patient is in good

* Notes on the cultural reactions of staphylococci and *B. coli* isolated from bone will be found in Appendix II.

condition, the trauma confined to the actual surface of section, the blood-supply intact, and the infection limited to the ordinary pyogenic organisms found in wounds.

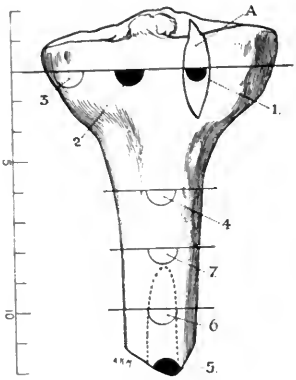


FIG. 212.

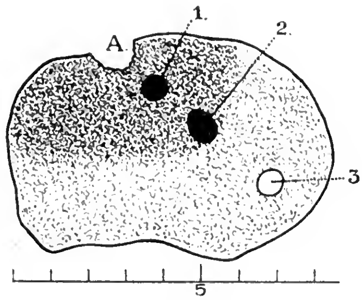


FIG. 213.

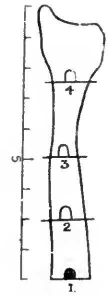


FIG. 214.

FIG. 212.—*Case* 7. Tibia from flapless amputation exposed to infection about 10 days. Organisms confined to cut surface. Gutter wound of anterior aspect of upper end has allowed penetration of organisms to 2 cm.
FIG. 213.—*Case* 7. Transverse section of tibia at level of (1), (2), (3). A, Fracture.
FIG. 214.—*Case* 7. Fibula from flapless amputation exposed to infection for about 10 days. Organisms confined to cut surface.

Table 4.—Case 7.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA*	ANAEROBIC BACTERIA*
Tibia 1	0·5 cm.	Streptococcus Staphylococcus Yeast	+ (including *B. perfringens*)
,, 2	2·0 ,,	Streptococcus	0
,, 3	4·5 ,,	0	0
,, 4	2·5 ,,	0	0
,, 5	Surface	Streptococcus Staphylococcus *B. mycoides* Yeast	+ (including *B. perfringens*)
,, 6	1·5 cm.	0	0
,, 7	3·5 ,,	0	0
Fibula 1	Surface	Staphylococcus	—
,, 2	2·0 cm.	0	—
,, 3	4·1 ,,	0	—
,, 4	6·5 ,,	0	—
Knee-joint at amputation	..	Streptococcus	0
Blood from vein at amputation	..	0	—

Exposure of bone to sepsis.—About 10 days.
Amputation.—June 2, 1916, 11.20 p.m.
First culture taken from bone.—June 3, 12.40 a.m.
Last culture taken from bone.—June 3, 2.5 a.m.
Order of cultures.—Fibula: 1, 2, 3, 4. Tibia: 3, 2, 1, 4, 7, 6, 5.

* In this and the following tables, + = Growth of anaerobes; 0 = Absence of growth; — = Culture not made.

Case 7.—Lieut. A., age 25. [*Ref. No*, 202.]

Lesion.—Gutter of articular border of tibia, involving knee-joint.

Clinical History.—Flapless amputation 12 cm. below knee-joint at casualty clearing station for bomb wounds of leg. Re-amputation above knee at base hospital for streptococcal arthritis of knee (*Figs*. 212, 213, 214).

These bones show that in amputation through normal shaft under the simplest conditions, organisms do not penetrate far below the surface. The invaded bone is, however, softened, and this process of penetration by organisms is possibly associated with the formation of the superficial sequestrum which frequently separates at a later date. (See *Case* 6, Appendix I, for similar conditions in cancellous tissue, and *Case* 8, Appendix I, in which the conditions as regards the bone were identical, but in which drainage of the soft parts was not sufficiently free to allow of saving the limb.)

FACTORS INFLUENCING PENETRATION OF BONE BY BACTERIA.

Analysis of the material examined shows that a number of factors operate to influence the process of penetration, and that they are frequently found in varying combinations. The discussion of the factors which have been kept in view as possibly influencing penetration is arranged as follows :—

1. Structural and anatomical variety of bone.
2. Extent and degree of injury.
3. Types of bacteria.
4. Infection of the surrounding soft parts.
5. Diminution of blood-supply :
   - *a.* Local : Interruption of the main artery of the limb : Interruption of the chief artery to the bone ; Interruption of the medullary artery at the site of fracture.
   - *b.* General : Death ; Hæmorrhage following operation ; and Secondary hæmorrhage.
6. Surgical treatment of wounds.
   - *a.* Penetration in fracture with untreated bone : Early ; and Late.
   - *b.* Penetration with obstruction of drainage : (i) Influence on penetration of inadequate drainage of soft parts ; (ii) Influence on penetration of inadequate drainage of bone.
   - *c.* Penetration in presence of undrained fissure.
   - *d.* Penetration in well-drained bone with reinforcement of sepsis from the soft parts.
   - *e.* Absence of penetration with free drainage of bone and soft parts.
7. Time.

1. **Influence of the Structural and Anatomical Variety of Bone.**—We have found no evidence that the marrow of the shaft differs materially in its reaction to penetration from the cancellous bone of the articular ends, nor has any difference been noted between individual bones.

2. **Influence of the Extent and Degree of Injury.**—In untreated cases, while the whole surface of the fracture is potentially a source of penetration, the actual track or resting-place of the missile is the most favourable

point of departure, on account of the presence of infected débris on the surface of the bone. If this is removed, there is no evidence that the subjacent bruise facilitates penetration.

3. **Estimate of the Power of Penetration possessed by each Bacterial Group.**—Since the frequency-data presented in *Table* I are based on the results of cultivating at various distances from the site of the fracture, they may be presumed to give an indication of the penetrating capacity of the invading bacteria. Direct evidence is obtainable by measurement of the extreme limit of penetration in a series of cases, and by taking an average for each group of organisms. This has been done, with the following results (three bones giving very mixed growths are excluded): (*a*) The average distance of penetration of the streptococcus in ten cases is 2·0 cm. (*b*) The average distance of penetration of the staphylococcus in ten cases is 1·5 cm. (*c*) The average distance of penetration of anaerobes in six cases is 0·8 cm. (*d*) The average distance of penetration of *B. coli* in three cases is 0·7 cm. The two sets of observations are mutually confirmatory, and justify the conclusion that they are an expression of the penetrating capacities of the bacterial groups concerned. *Cases* 9 and 10, Appendix I, illustrate the low penetrating power of *B. coli.*

It has not been possible to make an exact study of the anaerobes met with in bone, but it is apparent that the *B. perfringens* has less tendency to penetrate bone than other types of anaerobe. Thus, of 20 bones examined, out of 16 cultures growing anaerobes from the surface of the lesion, 8 yielded *B. perfringens* (50 per cent); while out of 29 cultures growing anaerobes at various levels, *B. perfringens* was present in 7 (24 per cent).

4. **Infection of Soft Parts.**—It is evident that penetration in fractured bone cannot be dissociated from the conditions as regards infection of the surrounding soft parts, since the primary lesion of the bone is an integral part of the wound, and is therefore liable to receive reinforcement of sepsis from inadequately drained recesses. This question is intimately connected with the influence of surgical treatment of the wound on penetration, and its further discussion here is unnecessary.

5. **Effect of Diminution of the Blood-supply.**—As in the soft parts, any considerable diminution of the blood-supply to bone is immediately reflected in an increased growth of bacteria, especially anaerobes. There are two conditions under which this occurs, namely: (*a*) Local diminution; (*b*) General diminution.

a. Local Diminution of Blood-supply.

i. *Interruption of the Main Artery of the Limb.*

Case 11.—Major S., age 33. [*Ref. No.* 206.]

Lesion.—Perforating high-explosive shell wound of elbow, with superficial fracture of under surface of coronoid process of ulna.

Clinical History.—Dec. 25, 1916, severe multiple wounds. Elbow track cleaned out at casualty clearing station, and brachial artery tied. Elbow remained normal till Jan. 16, 1917, when patient complained of severe pain in joint, which showed the physical signs of acute arthritis. Immediate resection of head of ulna and radius. Humerus intact, not interfered with.

Examination of Parts Removed, Jan. 16.—Under surface of coronoid process bare. No breach of cartilaginous surface of ulna. Capsule soft and infiltrated

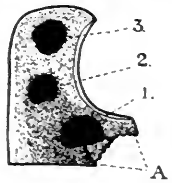


Fig. 215.—*Case* 11. Olecranon process removed by operation 22 days after injury. Temporary interference with blood-supply by ligature of brachial artery.

where attached to edge of coronoid process, and infection probably reached joint by this route (*Fig.* 215).

Table 5.—*Case* 11.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Ulna 1	In fissure	Streptococcus	0
,, 2	1·6 cm.	,,	0
,, 3	2·5 ,,	,,	0
Elbow-joint at operation	..	,,	0
Blood from vein, Jan. 12	..	0	—
,, ,, Jan. 21	..	0	—

Exposure of bone to sepsis.—22 days.
Resection.—4.0 p.m.
Bone in ice.—From 4.5 p.m. to 5.45 p.m.
First culture taken from bone.—6.10 p.m.
Last culture taken from bone.—6.21 p.m.
Order of cultures.—3, 2, 1.

Owing to the ligature of the brachial artery in the wound in this case, the blood-supply of this portion of the bone was temporarily interfered with, although at no time was there any serious inadequacy of the circulation through the forearm.

ii. *Interruption of the Chief Artery to the Bone.*—Two cases of wounds of the os calcis illustrate this point, the wounds and general condition of the patients being sufficiently similar to eliminate any other influence adequate to explain the discrepancy. The blood-supply of this bone is derived almost entirely from the posterior tibial artery. Where this artery was intact (*Case* 12), penetration was limited to the immediate neighbourhood of the fracture. Where the artery was divided (*Case* 13), penetration of organisms was found throughout the whole bone.

Case 12.—Lieut. L., age 22.

Lesion.—Perforating shell-wounds of ankle. Compound fracture of tibia, fibula, astragalus, and os calcis. Ankle-joint open. Astragalo-calcanean joint full of blood.

Clinical History.—Wounded Sept. 15, 1916, at night. Wounds packed with gauze at casualty clearing station. On arrival at base hospital, very ill, skin jaundiced, partly conscious. Amputation 15 cm. above malleoli on Sept. 18 at 11.0 a.m., two and a half days after infliction of wound. Death two hours later.

Clinical Picture.—Anaerobic toxæmia.

Examination of Foot, Sept. 18, 5.40 p.m.—Perforating wound at level of inferior tibiofibular joint, involving both bones, opening ankle, and grazing astragalus. This wound contained mud and cloth beneath the gauze pack. Separate perforating wound of os calcis, with entry below posterior end of sustentaculum tali, and exit at peroneal spine. Soft parts of foot swollen, but not gangrenous. No gaseous cellulitis. (*Figs.* 216, 217, and 208.)

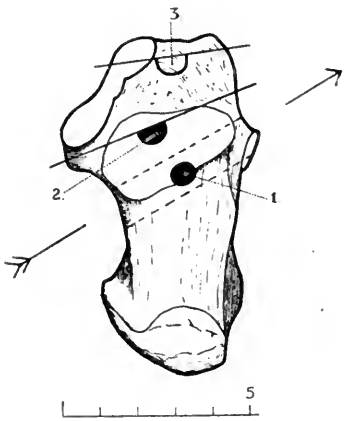


FIG. 216.

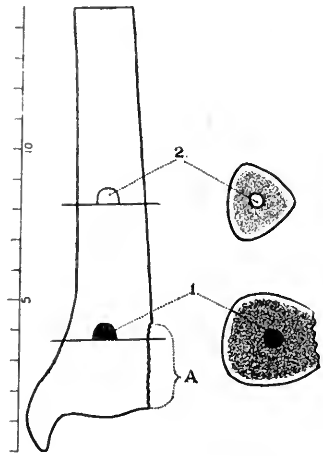


FIG. 217.

FIG. 216.—*Case* 12. Os calcis with perforating shell-track removed by amputation 2½ days after injury. Posterior tibial artery intact. Penetration to 0·5 cm.

FIG. 217.—*Case* 12. Tibia with gutter fracture, same limb as *Fig.* 216. Penetration to 1 cm.

Table 6.—*Case* 12.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1	1·0 cm.	Staphylococcus	+
,, 2	4·2 ,,	0	0
Calcaneum 1	Surface	0	+ (including *B. perfringens*)
,, 2	0·5 cm.	0	+
,, 3	1·8 ,,	0	0
Blood from vein at amputation	..	0	+

Exposure of bone to sepsis before amputation.—2½ days.
Bone in ice.—From 11 a.m. to 5.30 p.m.
First culture taken from bone.—5.40 p.m.
Last culture taken from bone.—6.30 p.m.
Order of cultures.—Tibia : 1, 2. Calcaneum : 3, 2, 1.

Note.—The bacillus isolated in pure culture from the blood and from Tibia 1 and Calcaneum 2 was a non-proteolytic anaerobe morphologically resembling *B. perfringens*, but differing from it in not producing the 'stormy fermentation' reaction in milk.

Case 13.—Lieut. R., age 41.

Lesion.—Multiple high-explosive shell wounds. Right foot: Anterior half shattered. Right leg: Perforating flesh wound 10 cm. above ankle, dividing posterior tibial artery. Right knee: Small penetrating wound, with shell fragment embedded in internal condyle of femur. Other minor flesh wounds.

Clinical History.—Wounded Oct. 22, 1916. Operation at casualty clearing station, Oct. 23, confined to cleaning all flesh wounds and disarticulation at right tarsometatarsal joint. Right knee not touched. Arrived at base Oct. 27. Temperature 102·4°, pulse 120. Right knee quiet. Amputation in lower third of thigh for streptococcal arthritis, Oct. 29, 11.25 a.m. Death Oct. 30, 5.30 a.m.

Clinical Picture.—Septicæmia.

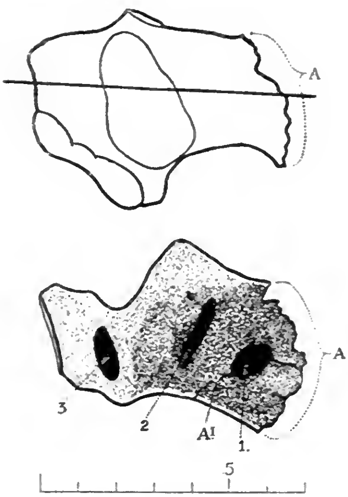


FIG. 218

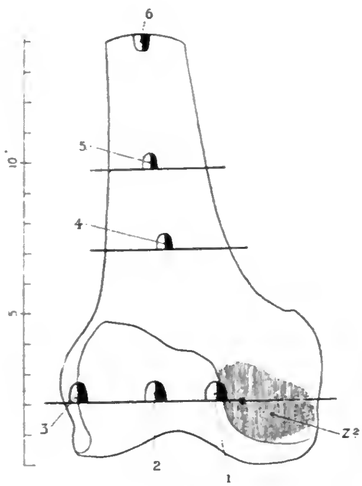


FIG. 219.

FIG. 218.—*Case* 13. Os calcis with shell wound of tuberosity removed by amputation 7 days after injury. Posterior tibial artery divided. Penetration of whole bone by anaerobes. (*Cf. Fig.* 216.)

FIG. 219.—*Case* 13. Lower end of femur removed by amputation 7 days after injury. Streptococcus in blood recovered from all parts of bone.

FIG. 220.—*Case* 13. Tracing of transverse section of femur shown in *Fig.* 219. Small shell-fragment with surrounding bruise. Streptococcus in blood recovered from injured and uninjured bone. Z^1, Soft bone probably infected from shell. Z^2, Hard bruised bone. Growth at (1) may be a local extension from shell.

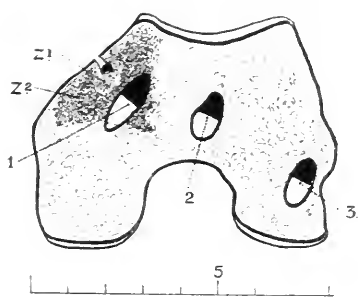


FIG. 220.

Examination of Limb, Oct. 29.—Foot: Surface of amputation covered with brown exudation—superficial necrosis. Foul wound of heel, with fracture[1] of tuberosity of os calcis. No gangrene or gaseous cellulitis. Leg: Septic tunnel through deep flexors, dividing posterior tibial artery. Knee: Skin puncture covered with small dry scab. Small hole in synovial membrane, through which the deeper part of the extra-articular track had become infected. Small shell-fragment embedded in anterior part of internal condyle at reflection of synovial membrane from bone to capsule. Surrounding bruise. Joint effusion, blood-stained. Os calcis and 14 cm. of femur examined for penetration by organisms. (*Figs.* 218, 219, 220.)

Table 7.—*Case* 13.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Os calcis 1	In fissure	Streptococcus, coliform bacillus	+
,, 2	0·7 cm.	Streptococcus, coliform bacillus	+
,, 3	2·1 ,,	Streptococcus, coliform bacillus	+
Femur 1	0·5 ,,	Streptococcus	0
,, 2	2·5 ,,	,,	0
,, 3	5·5 ,,	,,	0
,, 4	5·5 ,,	,,	0
,, 5	8·0 ,,	,,	0
,, 6	12·0 ,,	,,	0
Tibia (control)	..	,,	0
Knee-joint, Oct. 29	..	,,	0
Blood from vein $3\frac{1}{2}$ hours after amputation	..	,,	0

Exposure of bone to sepsis.—7 days.
Bones in ice.—From 11.45 a.m. to 5.30 p.m.
First culture taken from bone.—5.35 p.m. Last culture.—7.15 p.m.
Order of cultures.—Femur : 3, 2, 1, 4, 5, 6. Tibia. Os calcis : 3, 2, 1.

iii. *Interruption of the Medullary Artery at the Site of Fracture.*—The effect of this is seen in a more extensive growth of organisms in the fragment which is cut off from the medullary artery. (See also *Cases* 15 and 16, Appendix I.)

Table 8.—*Case* 14.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Upper fragment 1 ..	In fissure	Streptococcus	0
,, ,, 2 ..	1·5 cm.	,,	0
,, ,, 3 ..	3·5 ,,	0	0
,, ,, 4 ..	6·3 ,,	0	0
,, ,, 5 ..	10·3 ,,	0	0
,, ,, 6 ..	0·8 ,,	Streptococcus	0
Lower ,, 1 ..	In fissure	Streptococcus, *B. proteus*	0
,, ,, 2 ..	,, ,,	Streptococcus, *B. proteus*	0
,, ,, 3 ..	1·5 cm.	Streptococcus	0
,, ,, 4 ..	3·5 ,,	,,	0
,, ,, 5 ..	5·5 ,,	,,	0
,, ,, 6 ..	7·7 ,,	0	0
Femur (control) ..	..	0	0
Blood from vein, Feb. 20	..	0	—

Exposure of bone to sepsis.—31 days.
Amputation.—March 8, 2.30 p.m.
Bone in ice.—From 2.30 p.m. to 3.35 p.m., March 8.
First culture taken from bone.—3.50 p.m. Last culture.—5.0 p.m.
Order of cultures.—Lower fragment : 6, 5, 4, 3, 2, 1. Upper fragment : 6, 5, 4, 3, 2, 1. Femur.

Case 14.—Sec. Lieut. B., age 28. [*Ref. No.* 207.]

Lesion.—Multiple high-explosive shell wounds. Abdomen: Penetrating upper end of left linea semilunaris; no evidence of visceral injury. Sterile secondary effusion into left pleura. Left forearm: Extensor tendons of wrist divided; cellulitis of hand; fracture of olecranon. Right hernia testis. Left leg: Compound fracture of tibia and first metatarsal. Many minor wounds.

Clinical History.—Wounded Feb. 5, 1917. All wounds opened up and drained same day at casualty clearing station. Transferred to base Feb. 21. Still profoundly septic. Pockets of pus opened on two occasions. Amputation of left leg above knee was followed by rapid improvement in general condition and healing of all wounds. Transferred to England March 22.

Examination of Limb, March 8.—Three wounds of tibia. Main fracture exposed in wound of anterior aspect of leg. Bone dry and dead-looking where visible. Soft parts adherent to bone right up to fractured ends. No pocketing of pus. Muscles of leg œdematous, with commencing fibrosis in neighbourhood of fracture. Anterior and posterior tibial vessels intact. Upper and lower tibial wounds are small cracks at bottom of suppurating sinuses. (*Fig.* 221 and *Table* 8.)

b. Effect of General Diminution of Blood-supply.

1. *Death.*—The gradual failure of circulation which not uncommonly allows the extremities to become cold for many hours before death, is particularly favourable to the growth of anaerobes and other saprophytes. (See *Case* 4 (*Fig.* 247), Appendix I, of amputation followed by death, with anaerobic penetration of 24 cm.; and contrast it with *Case* 7 (*Fig.* 212), of surviving amputation, with anaerobes confined to surface.)

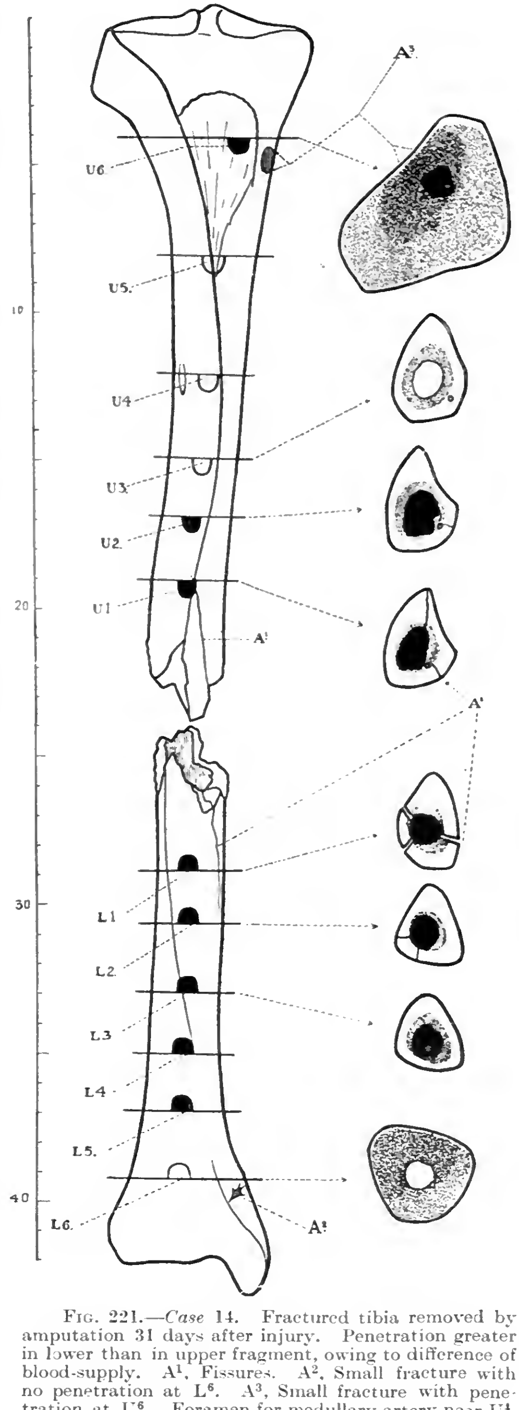


Fig. 221.—*Case* 14. Fractured tibia removed by amputation 31 days after injury. Penetration greater in lower than in upper fragment, owing to difference of blood-supply. A^1, Fissures. A^2, Small fracture with no penetration at L^6. A^3, Small fracture with penetration at U^6. Foramen for medullary artery near U^4. U, Upper fragment. L, Lower fragment.

2. *Hæmorrhage.*—After severe hæmorrhage the resistance of bone to penetration is reduced in association with the general diminution of the circulation.

i. *Hæmorrhage following Operation.*

Case 17.—Lieut. L., age 28. [*Ref. No.* 208.]

Lesion.—Superficial gutter of articular border of internal tuberosity of tibia, with tear of semilunar cartilage. Tangential blow by fragment of high-explosive shell, which remained extracapsular.

Clinical History.—Wounded July 3, 1916, 1 a.m. On July 6 arrived at base, 3 days 7 hours after being wounded. Joint effusion, consisting of blood-stained synovia contained staphylococcus.

First operation, July 6, 6.30 p.m. (3 days 17½ hours after wound).—Local excision of track, shell-fragment, fracture, and portion of semilunar cartilage. Joint closed after irrigation.

Second operation, July 12, 9.30 p.m. (9 days 20 hours after wound).—Resection of knee-joint, including the whole of tibial fracture. Joint effusion consisting of pus—staphylococcus.

July 13, cavity packed with gauze on account of persistent oozing of blood. July 16, pyocyaneus infection of cavity.

Third operation, July 18 (6 days after resection).—Amputation through resection wound.

Aug. 15, transferred to England. April, 1917, garrison duty abroad.

Examination of Limb after Removal, July 18.—Œdema of subcutaneous tissue. Muscles macroscopically normal. No pus outside resection cavity (*Figs.* 222, 223, and *Table* 9).

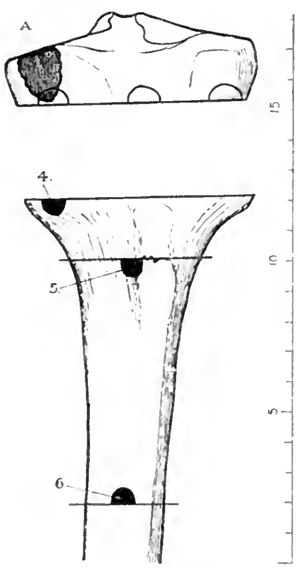


FIG. 222.

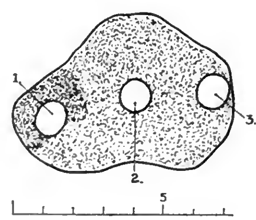


FIG. 223

FIG. 222.—*Case* 17. Tibia showing portions removed by resection and amputation. A, Original surface-wound from which no penetration occurred in ten days. After severe hæmorrhage which followed resection organisms penetrated to at least 10 cm.

FIG. 223.—*Case* 17. Tracing from lower surface of resected portion of tibia shown in *Fig.* 222. No penetration in 10 days.

This case illustrates the different degrees of penetration by organisms before and after a severe hæmorrhage. In the resected portion of the bone there was a fracture infected presumably by the staphylococcus, since that organism was present in the joint. After a period of nearly 4 days, during which penetration was possible, the surface of this fracture was removed entire by the gouge to a depth of 2 to 3 mm. After a further period of 6 days, during which the clinical appearance of a mild infection was present in the

wound, examination of the resected portion of bone showed that penetration of organisms had not reached a depth of 0·6 cm. (i.e., penetration was less than 1 cm. in 9 days). After the hæmorrhage there was penetration to at least 10 cm. in 6 days. It must, however, be pointed out that we have no knowledge of the penetrating power of *B. pyocyaneus*.

Table 9.—*Case* 17.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia resection 1	0·6 cm.	0	0
,, ,, 2	2·8 ,,	0	0
,, ,, 3	5·4 ,,	0	0
,, amputation 4	Surface	Staphylococcus, *B. pyocyaneus*	0
,, ,, 5	2·0 cm.	Staphylococcus, *B. pyocyaneus*	0
,, ,, 6	9·5 ,,	*B. pyocyaneus*	0
Blood from vein, July 24 ..	..	0	—
Knee-joint, July 6 and July 12	..	Staphylococcus	0

Exposure of tibia to sepsis between date of wound and date of resection of knee.—9 days.
Exposure of tibia to sepsis between resection and amputation.—6 days.
Resection.—10.30 p.m.
Bone in ice.—From 10.35 p.m. to 12.15 a.m.
First culture taken from bone.—12.25 a.m.
Last culture taken from bone.—12.35 a.m.
Order of cultures.—3, 2, 1.
Amputation.—5.45 p.m.
Bone in ice.—From 6.40 p.m. to 11.25 p.m.
First culture taken from bone.—11.30 p.m.
Last culture taken from bone.—12 midnight.
Order of cultures.—6, 5, 4.

ii. *Secondary Hæmorrhage.*

Case 15, examined twenty-four hours after severe *secondary hæmorrhage*, is described in Appendix I. Owing to division of the medullary artery, it is not possible to estimate the effect of the secondary hæmorrhage in the production of the extensive penetration observed.

6. **Influence of Surgical Treatment of Wounds on Penetration.**—The results obtained from the study of the material which forms the basis of this communication do not represent the natural history of untreated gunshot fracture. In the majority of cases it must be assumed that this has been modified by the ordinary surgical technique of cleansing and drainage of wounds.*

* By surgical cleansing is meant the removal of all dead tissue and foreign matter (mud, cloth, and missile) from a wound. By drainage is meant the establishment of free communication of all parts of the wound with the surface. The aim of these procedures is to prevent the saprophytic growth of bacteria in wounds which precedes parasitic invasion of the living tissues.

In none of the cases was any attempt made to bring about surgical sterilization of the wound by the continuous or intermittent instillation of antiseptics. The ordinary routine was as follows :—

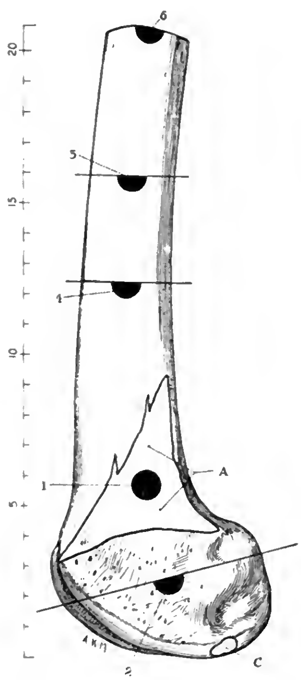
Soft Parts : The wound was excised or opened freely so as to allow of either gravity drainage by tubes, or gauze drainage of a funnel-shaped wound.

Bone : All comminuted cancellous tissue lying on the surface of the bone wound was removed by gouge or curette, on the assumption that such bone was killed by the direct effect of the missile, and consequently formed a suitable nidus for bacteria. The firm bruised portion was not removed. The treatment as a whole constitutes in effect the establishment of drainage for the bone.

a. Penetration in Fracture with Untreated Bone.

The following represent (i) Early, and (ii) Late stages in the evolution of an untreated septic fracture :—

i. *Early Stage.*—This is shown in *Case* 18, Appendix I.



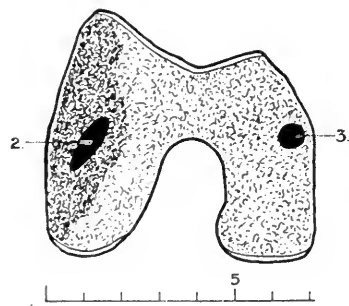
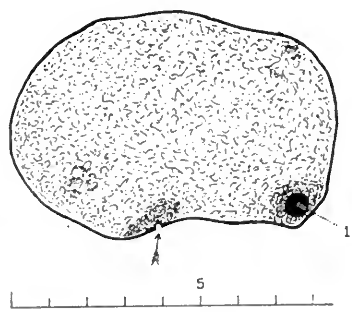


FIG. 225.



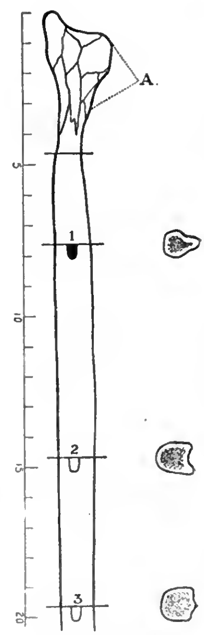


FIG. 224. FIG. 226. FIG. 227.

FIG. 224.—*Case* 19. Femur removed by amputation. No surgical interference with actual fracture. Growth throughout bone. A, Fracture.

FIG. 225.—*Case* 19. Transverse section of femur shown in *Fig.* 224 at level of (2). Growth throughout bruised and uninjured bone.

FIG. 226.—*Case* 19. Transverse section of upper end of tibia, showing penetration from small untreated fracture (indicated by arrow). Specimen 1 taken from indirect bruise beneath superior fibular facet. Specimen 2 in *Table* 10 was from opposite tuberosity 2 cm. lower.

FIG. 227.—*Case* 19. Fibula showing fracture of head, and associated penetration.

ii. *Late Stage.*—In the following case, and in *Case* 20, Appendix I, the interval which elapsed between wound and amputation is not known with certainty. From the data available it was between 7 and 14 days. In both cases the flesh wound had been partially opened up, but the bone had clearly not been interfered with in any way.

Case 19.—Pte. P.

Clinical History.—Amputation in lower third of thigh for suppurative arthritis of knee. Early tetanus with local spasm.

Examination of Limb after Removal.—Vertical gutter wound on outer side of knee, extending from upper border of patella to level of tibial tubercle. In the upper third of this was the mouth of a sinus leading down to a gutter fracture of the external condyle of the femur (*Fig.* 224). In the lower third was the mouth of a similar sinus leading to a small wound of the external tuberosity of the tibia. Behind this sinus the comminuted head of the fibula lay bare in the wound. Pus tracks from femur, 4 cm. upwards, deep to vastus externus; from tibia, one-third down leg, in anterior tibial compartment; from fibula, 5 cm. downwards, in subcutaneous tissue.

Knee-joint: no tension, free exit of pus through sinuses; articular cartilage—white, intact; synovial membrane—superficial sloughing; effusion—yellow pus; extracapsular extension of pus—nil; popliteal space—intact; no foreign body. (*Figs.* 224, 225, 226, 227.)

Table 10.—*Case* 19.

Specimen taken for culture	Distance from lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	Surface	Streptococcus, coliform bacillus, Gram + diplococcus	+ (including *B. perfringens* and tetanus-like bacillus)
,, 2	1·4 cm.	Streptococcus, coliform bacillus, minute Gram + diplococcus, minute Gram + staphylococcus	+
,, 3	4·7 ,,	Streptococcus, coliform bacillus, minute Gram + diplococcus, minute Gram + staphylococcus	+ (including tetanus-like bacillus)
,, 4	2·8 ,,	Coliform bacillus, minute Gram + staphylococcus	+
,, 5	6·1 ,,	Coliform bacillus	0
,, 6	11·0 ,,	Coliform bacillus	0
Tibia 1	3·3 ,,	Coliform bacillus, Gram + diplococcus, Gram + slender bacillus in chains	+
,, 2	3·5 ,, (about)	Coliform bacillus, Gram + diplococcus, Gram + slender bacillus in chains	+ (including *B. perfringens*)
Fibula 1	3·6 cm.	Coliform bacillus	0
,, 2	10·2 ,,	0	0
,, 3	15·6 ,,	0	0
Knee-joint	..	Streptococcus, coliform bacillus	+ (including *B. perfringens*)

Amputation.—June 23, 1916, 11.40 a.m.
Limb in ice.—From 12 noon to 3.30 p.m., June 23.
First culture taken from bone.—4.0 p.m.
Last culture taken from bone.—7.0 p.m.
Order of cultures.—Femur: 6, 5, 4, 1, 3, 2. Tibia: 1, 2. Fibula: 1, 2, 3.

This case, and *Case* 20, Appendix I, suggest that the presence of the dead comminuted surface-layer of cancellous bone facilitates the growth of a mixture of organisms, and that, in consequence of the unchecked proliferation on such a surface, extensive penetration occurs.

b. Penetration with Obstruction of Drainage.

As a general principle it may be stated that, in a septic flesh wound infiltration of the walls by organisms is in inverse proportion to freedom of drainage.

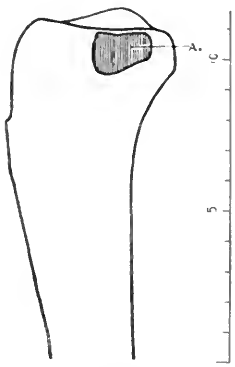


Fig. 228.

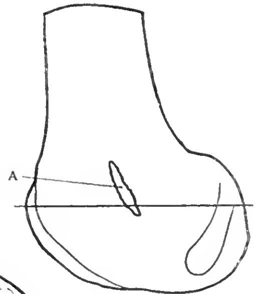
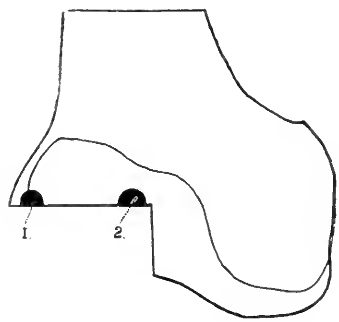


Fig. 230.



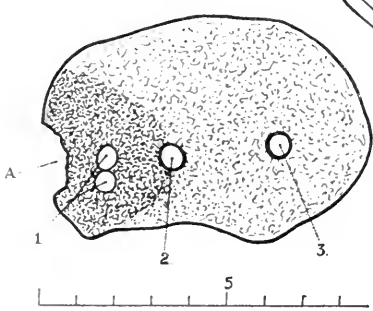


Fig. 229.

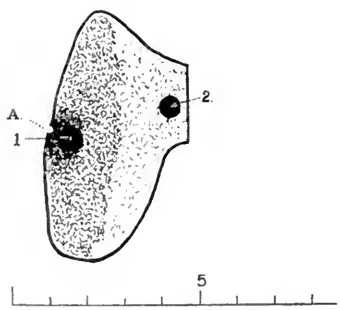


Fig. 231.

Fig. 228.—*Case* 21. Size and position of tibial wound (surface gutter).

Fig. 229.—*Case* 21. Tracing of transverse section through tibial wound shown in *Fig.* 228. Removed by amputation 16 days after injury. No penetration with free drainage. A, Wound.

Fig. 230.—*Case* 21. Size and position of femoral wound. Obstruction of drainage by knee-joint between fracture and surface.

Fig. 231.—*Case* 21. Tracing of section of femoral condyle through wound shown in *Fig.* 230. Penetration to at least 2·8 cm. from wound with obstructed drainage. Limit not reached.

In bone wounds, apart from untreated fractures, it is difficult to obtain examples of obstruction of drainage, for the reason that only some unusual combination of circumstances can afford the opportunity.

The following have been met with in our experience :—

i. *Influence on Penetration of Inadequate Drainage of Soft Parts.*

Infected amputation stump closed by suture of the flaps (*Case* 4. Appendix I). The primary effect of closure of the stump on penetration was overshadowed by the terminal stages of the disease.

Interruption of the drainage track by an infected joint through which a continuous feed of streptococcus led to increase of penetration (*Case* 21). This case affords a comparison between two similar wounds with different degrees of drainage in the same patient. The tibial wound was close to the surface, well open, and had had the superficial damaged bone removed by curetting. The femoral wound communicated with the surface by a narrow track, across the course of which lay the infected knee-joint. The drainage of this wound was not only obstructed, but a continuous reinforcement of its surface infection took place from the neighbouring joint. The foreign body and superficial layer of damaged bone had not been removed.

Case 21.—Major G., age 36. [*Ref. No.* 211.]

Lesion.—Small surface gutter of tibia, not communicating with knee-joint. Small perforating wound of knee-joint, with crack of external condyle of femur near attachment of lateral ligament. Shell fragments in both bones. Numerous other wounds from fragments of high-explosive shell.

Clinical History.—Wounded June 2, 1916. No operation before arrival at base on June 4, when all wounds except that into knee-joint were opened up, cleaned, and foreign bodies removed. Aspiration of knee-joint on account of increased effusion: turbid yellow fluid—streptococcus—June 12. Tibial wound excised and bone curetted. Track to knee-joint excised. HClO irrigation. Synovial membrane closed. Wound packed June 14. Amputation above knee June 18, 2.30 p.m. Transferred to England July 4. (*Figs.* 228, 229—Drainage good. *Figs.* 230, 231—Drainage obstructed.)

Table 11.—*Case* 21.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	0·7 cm.	0	0
,, 2	2·4 ,,	0	0
,, 3	5·2 ,,	0	0
Femur 1	0·2 ,,	Streptococcus	0
,, 2	2·8 ,,	,,	0
Knee-joint, June 12 ..	..	,,	0
,, June 13 ..	..	..	0
,, June 16 ..	..	,,	0
Blood from vein at amputation	..	0	0

Exposure of bones to sepsis.—16 days.
Dissection of limb commenced.—3.0 p.m., June 18.
Last culture taken from bone.—5.20 p.m.
Order of cultures.—Tibia : 3, 2, 1. Femur : 2, 1.

ii. *Influence on Penetration of Inadequate Drainage of Bone* (*Case* 22).

In this case three bones opened into a single septic cavity, but while the drainage of the radius and ulna was as complete as possible, that of the humerus was limited to a small opening in the articular surface.

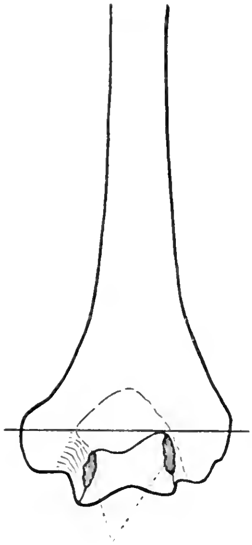


Fig. 232

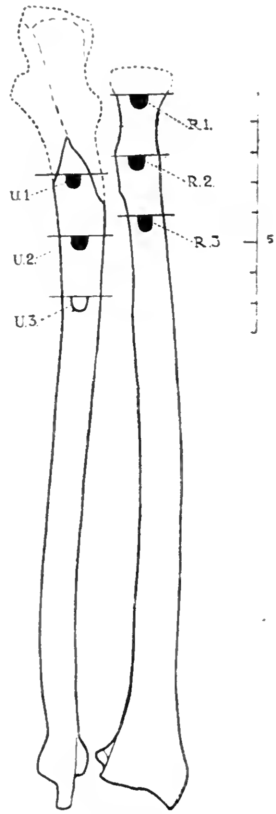


Fig. 233.

Fig. 232.—*Case* 22. Lower part of humerus removed by amputation 18 days after injury, showing small fractures. Purulent cancellous osteitis at level of section due to obstructed drainage of bone. Pure staphylococcus infection.

Fig. 233.—*Case* 22. Forearm bones removed by amputation: radius 16 days after resection of uninjured head: ulna 18 days after gunshot fracture. Penetration limited to 4 cm.; absence of macroscopic osteitis associated with free drainage of bones.

Table 12.—*Case* 22.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Humerus	At level of section of condyles	Staphylococcus	0
Radius 1	Surface	,,	0
,, 2	2·0 cm.	,,	0
,, 3	4·0 ,,	,,	0
Ulna 1	Surface	,,	0
,, 2	1·2 ,,	,,	0
,, 3	3·2 ,,	0	0
Elbow-joint, May 30	..	Staphylococcus, *B. coli*	0
,, May 31	..	,, ,,	0

Exposure of bones to sepsis.—Radius, 16 days; humerus and ulna, 18 days.
Amputation.—5.15 p.m. Humerus culture taken.—5.15 p.m.
First culture taken from radius.—6.30 p.m. Last culture taken from ulna.—7.5 p.m.
Order of cultures.—Humerus. Radius: 1, 2, 3. Ulna: 1, 2, 3.

Direct smear from sawn humerus showed pus cells and staphylococci.
The original tube of Radius 3 containing the bone-fragment grew, whilst a sample sub-cultured at once from this did not, showing that few organisms were present, and suggesting that this section was near the limit of penetration.

Case 22.—Lieut. G., age 22. [*Ref. No.* 212.]

Lesion.—High-explosive shell wound over olecranon process. Comminution of upper extremity of ulna. Chip from edge of trochlea of humerus. Radius uninjured.

Clinical History.—Wounded May 13, 1916, at night.

Operation, May 15.—Resection of comminuted portion of ulna and head of radius. Chipped edges of trochlea curetted. Exposed cancellous bone of humerus bruised. Drainage and irrigation of wound. Second operation, May 31.—Purulent cancellous osteomyelitis of humerus. Pus extended to upper limit of cancellous bone. Lower part of medulla looks infected, but is not purulent. Healthy bleeding marrow reached at middle of shaft. Amputation at this level, 5.15 p.m. Transferred to England June 12. Sequestreetomy, July 27, Sept. 17, and Jan. 6, 1917. Discharged from hospital Jan. 22, with healed wound and useful stump.

Clinical Picture.—Osteomyelitis.

Examination of Limb, May 31, 1916. No pus apart from humerus. Œdema of arm, but not of forearm. (*Figs.* 232, 233, and *Table* 12.)

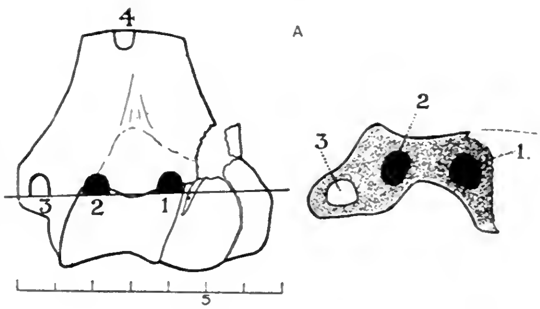
c. Penetration in Presence of Undrained Fissure.

Case 23.—Lieut. C., age 40. [*Ref. No.* 213.]

Lesion.—Fracture of external condyle of humerus, with crack into elbow-joint. Other minor flesh-wounds from high-explosive shell.

Clinical History.—Wounded Dec. 12, 1916. Shell fragments removed at base Dec. 16. Local operation on elbow wound, drainage improved and fracture curetted, elbow-joint not infected Jan. 1, 1917. Resection for arthritis of elbow Jan. 14. Transferred to England Feb. 14.

Although interference with the local blood-supply in the neighbourhood of the external condyle may have facilitated penetration, the chief factor was probably the feed of organisms from the imperfectly drained fissures shown in the diagram (*Fig.* 234).



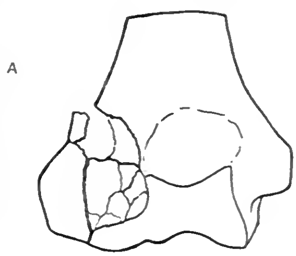


Fig. 234.—*Case* 23. Lower end of humerus removed by operation 33 days after injury.

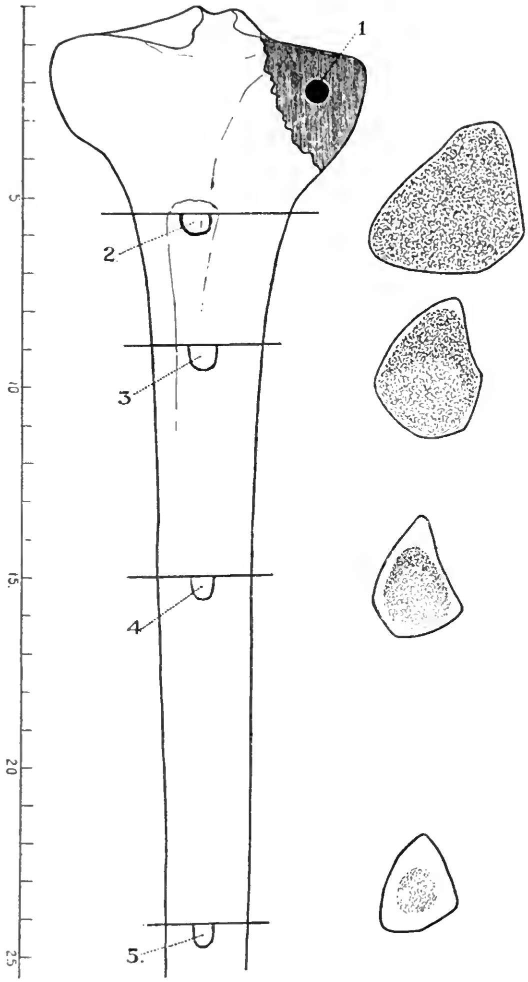
Anterior and posterior views, and tracing from transverse section. Penetration to 1·6 cm. in presence of undrained fissures. A, Fracture.

Table 13.—*Case* 23.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Humerus 1	0·3 cm.	Streptococcus	0
,, 2	1·6 ,,	,,	0
,, 3	3·3 ,,	0	0
,, 4	3·0 ,,	0	0
Ulna (control)	..	0	0
Blood from vein at amputation	..	0	0

Exposure of bone to sepsis.—33 days. Resection.—3.30 p.m., Jan. 14, 1917.
Bone in ice.—From 3.30 p.m. to 5.30 p.m., Jan. 14.
First culture taken from bone.—5.45 p.m. Last culture.—6.20 p.m.
Order of cultures.—Humerus: 4, 3, 2, 1. Ulna.

d. Penetration in Well-drained Bone with Extensive Reinforcement of Sepsis from the Soft Parts.



Case 24.—Pte. H. [*Ref. No.* 214.]

Clinical History.—Wounded May 13, 1916. Amputation May 17, 5.30 p.m.

Lesion.—Large foul wound of inner side of knee, opening joint. Comminution of internal condyle of tibia and femur.

Examination of Limb, May 17, 7.30 p.m.—Wound extended from inner border of patella to inner hamstrings. Joint widely open and contained a little brownish pus. Cartilage not eroded. No extracapsular extension of pus apart from wound, and no œdema of leg. Large foul pus-cavity extended up to level of amputation between vastus externus and femur; this was an extension from the original wound. (*Fig.* 235 and *Table* 14.)

With this last case may be compared the original tibial wound of *Case* 7. In both instances pus from the knee-joint flowed over the fracture on its way to the surface, and in

Fig. 235.—*Case* 24. Tibia removed by amputation 4 days after injury. Shell wound of internal tuberosity. Bruise extends to Section 4 (11·4 cm. from fracture). Penetration less than 3 cm. in well-drained bone with reinforcement of sepsis from soft parts.

Table 14.—*Case* 24.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	Surface	Streptococcus, coliform bacilli	+
,, 2	2·9 cm.	0	0
,, 3	5·5 ,,	0	0
,, 4	11·4 ,,	0	0
,, 5	21·0 ,,	0	0
Knee-joint pus ..	..	Streptococcus, coliform bacilli. Gram – cocci	+ (including *B. perfringens*)

Exposure of bone to sepsis.—4 days.

Case 24 there was a further addition of sepsis from a large cavity in muscle. In spite of this, the freedom of drainage of the bone was adequate to prevent extensive penetration.

e. Absence of Penetration with Free Drainage of Bone and Soft Parts.

An example of this is given in the tibial wound of *Case* 21.

The series of cases described above shows that the degree of penetration is inversely proportional to the adequacy of drainage established by surgical interference. An estimate of the depth to which uncomminuted, bruised, cancellous bone requires removal by operation should be based upon a consideration of the factors which have been shown to influence penetration, especially the extent and intensity of infection of the soft parts and the length of time during which the wound has remained untreated since infliction. Bruising, *per se*, is not an indication for removal of bone.

7. **Influence of Time on Penetration.**—In estimating the relationship between the length of time during which a bone is exposed to infection and the degree of penetration by organisms, cases in which growth is clearly enhanced by diminution of blood-supply or by obstruction of drainage must be excluded.

In *Table* 15 are grouped 16 observations on bones in which no complications are introduced by these factors.

Table 15.—Showing the Relation between Time and Penetration.

Case	Bone	Time	Penetration	Sterile at	Organisms at Limit
12	Calcaneum	2·5 days	0·5 cm.	1·8 cm.	Anaerobes
12	Tibia	2·5 ,,	1·0 ,,	4·2 ,,	Staphylococcus, anaerobes
26	Humerus	3 ,,	Surface	0·5 ,,	Staphylococcus, anaerobes
18	Femur	3·5 ,,	0·8 cm.	1·9 ,,	Anaerobes
24	Tibia	4 ,,	Surface	2·9 ,,	Streptococcus, coliform bacilli
7	Tibia	10 ,,	2·0 cm.	2·5 ,,	Streptococcus
7	Tibia (amputatn.)	10 ,,	Surface	1·5 ,,	Mixed
7	Fibula ,,	10 ,,	Surface	2·0 ,,	Staphylococcus
9	Tibia	14 ,,	0·8 cm.	4·7 ,,	*B. coli*, anaerobes
6	.. (amputation)	16 ,,	1·5 ,,	4·0 ,,	Streptococcus, staphylococcus
21	,, ...	16 ,,	Surface	0·7 ,,	Streptococcus
8	,, ...	23 ,,	2·0 cm.	11·2 ,, (no section made between 2 and 11 cm.)	,,
23	Humerus	23 ,,	1·6 ,,	3·3 cm.	,,
25	Femur	26 ,,	Surface	1·5 ,,	,,
14	Tibia, upper fragment ..	31 ,,	1·5 cm.	3·5 ,,	,,
14	,, head ..	31 ,,	0·8 ,,	3·0 ,,	,,

Although the number is too small to allow of detailed analysis, a general consideration of the table brings out two points: Firstly, cases in which organisms are confined to the surface are equally spaced over the first four weeks. The continued presence of organisms in contact with open bone does not, therefore, necessarily lead to infection of the deeper layers. Secondly, if the average depth of penetration reached in the first week be compared with the average depth reached during the succeeding four weeks, the process does not appear to be one of uncontrolled progression. Thus, the average penetration by organisms in the first week is 0·46 cm. (five observations),

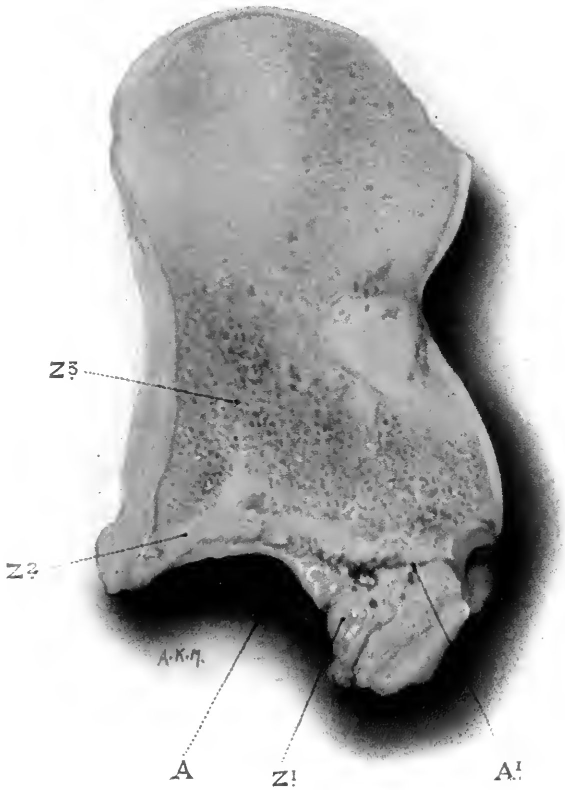


FIG. 236.

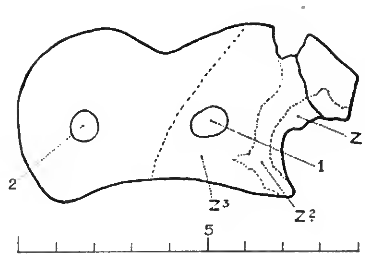


FIG. 237

FIG. 236.—*Case* 25. Upper surface of lower extremity of femur resected 26 days after injury.
A, Original shell-wound curetted 2 days after infliction. A1, Fissure through which streptococcus reached knee-joint. Z1, Granulation tissue resting on a thin layer of bone which contained pus cells and streptococcus. Z2, Fibrous tissue filling cancellous spaces; deep to this the bone was softer than normal. Z3, Bone of normal consistence; red colour probably due to inflammatory hyperæmia, but may be partly residual from original bruise. Beyond this, normal bone. (*See key figure—Fig.* 237.)

FIG. 237.—*Case* 25. Tracing from bone shown in *Fig.* 236. Z1, Granulation tissue lining original wound. Z2, Zone of sclerosed bone. Z3, Zone of hyperæmia. 1, Junction of hard and softened bone. 2, Normal hard bone.

while the average additional penetration during the succeeding four weeks is 0·46 cm. (eleven observations). These figures suggest that, where penetration beneath the surface occurs, the rate is greater during the first few days than during the succeeding weeks.

Although there is no evidence as to the mechanism by which the slowing of the rate of penetration is brought about, it is natural to suppose that it is in the nature of an immunity reaction. At a later date the development of a defensive reaction associated with the process of repair is suggested by the conditions found in *Case* 25, the only instance met with in the series.

Case 25.—Sec.-Lieut. B., age 22. [*Ref. No.* 215.]

Lesion.—High-explosive shell wound of internal condyle of femur. Fissure into knee-joint.

Clinical History.—Wounded Aug. 4, 1916. Two days afterwards the shell fragment was removed and its site curetted at a casualty clearing station. Arrived at base nine days after being wounded, with streptococcal arthritis of knee. Limb immobilized. Resection of knee-joint Aug. 30, twenty-six days after being wounded. Transferred to England. Limb still in plaster, April, 1917.

Joint at Resection.—Cartilage: eroded at points of pressure. Synovial membrane: surface replaced by soft granulation tissue. Effusion: pus. Extracapsular extension: nil. Periarticular œdema: considerable.

Examination of Bone Removed, Aug. 30 (*Figs.* 236 and 237).—The surface illustrated in *Fig.* 236, when examined with a dissecting microscope, showed that the grey zone deep to the layer of granulations consisted of two areas: (1) A narrow superficial strip showing definite osteomyelitis, especially near the fissure—i.e., the cancellous spaces were filled with pus; (2) Deep to this a dense white zone, the cancellous spaces of which looked solid in contrast with the empty cancellous spaces of the adjacent red area. Considerable numbers of streptococci were found in the pus of the superficial area, and although it was difficult to obtain a good smear, none were seen in the sclerosed area. The red cancellous bone deep to the sclerosed zone was softened as far as Specimen 1, which was taken at the junction of hard and soft bone.

Table 16.—*Case* 25.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1 (soft bone) ..	1·5 cm.	0	0
,, 2 (hard ,, ..	4·9 ,,	0	0
Knee-joint, Aug. 13 ..	..	Streptococcus	0
,, Aug. 21 ..	..	..	0

Exposure of bone to sepsis.—26 days.
Resection.—3.30 p.m.
Bone in ice.—From 3.30 p.m. to 6.30 p.m.
First culture taken from bone.—6.40 p.m.
Last culture taken from bone.—6.45 p.m.
Order of cultures.—2, 1.

IV. EXTENSION OF INFECTION ALONG OPEN FISSURES.

A fissure whose walls are not in contact affords ample opportunity for the growth of any organisms which may be present in the wound, as it provides a cavity with rigid walls, full of blood-clot, and defiant of drainage. Its behaviour can be studied clinically in an infected fracture of the femur, accompanied by fissuring, where the incisions for drainage have been confined to the region of complete solution of continuity. The fissure, full of blod-clot, is then in communication at one end with the wound flora, and at the other end opens either into a muscle or joint-cavity.

Organisms grow along the fissure from the point of primary infection, and since lateral penetration of the bone by organisms, and toxic absorption from the walls of the fissure, are comparatively slight, the process of extension is not reflected to a noticeable degree in the temperature chart, pulse-rate, or general

condition of the patient. As soon, however, as bacteria escape from the fissure into an adjacent muscle or joint-cavity, the clinical picture changes to that associated with pocketing or with the development of a septic arthritis.

The absolute rate of travel of organisms along a fissure can only be determined by the bacteriological examination of serial sections of bones removed by operation. Estimates of the apparent rate of travel have been founded, from a clinical point of view, on the appearance of infection in a joint at the far end of a fissure. This use of a joint as an indicator is probably fallacious, since it implies the assumption that no delay occurs at the breach in the synovial surface. Delay is known to occur in the case of anaerobes and the staphylococcus (see *Case* 27), and probably happens in a less degree in the case of the streptococcus, although the material available does not allow of precise statement with regard to this organism.

The two methods are illustrated in *Cases* 26 and 27. *Case* 27 also illustrates the persistence of anaerobes in a fissure after they have disappeared from the original wound.

Examination of a Fissure at an Early Stage before Extension has taken place.

Case 26.—Sec.-Lieut. B., age 35. [*Ref.* 216.]

Lesion. — Neck of humerus shattered by rifle bullet. Gas infection of soft parts.

Clinical History. — Wounded Sept. 14, 1916. Limited excision of surface wound, with tube drainage, at casualty clearing station. Rapid swelling of shoulder. *X* rays showed that the fissure extended to the shoulder-joint. Sepsis rapidly subsided after resection on Sept. 17, 4.15 p.m. Transferred to England Oct. 1. (*Fig.* 238).

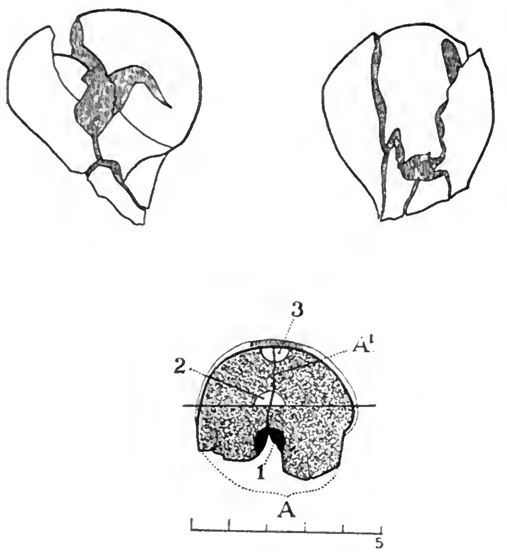


Fig. 238.—*Case* 26. Head of humerus removed by operation 3 days after injury. Anterior and external views and section. A, Main fracture of surgical neck. A¹, Fissure, showing no extension of organisms. Whole head bruised.

Table 17.—*Case* 26.

Specimen taken for Culture		Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Humerus 1	..	Surface	Staphylococcus	+
,, 2	..	0·5 cm.	0	0
,, 3	..	1·8 ,,	0	0

Exposure of bone to sepsis.—3 days.
Bone in ice.—From 4.20 p.m. to 6.10 p.m., Sept. 17.
First culture taken from bone.—6.20 p.m.
Last culture taken from bone.—6.45 p.m.
Order of cultures.—3, 1, 2.

Examination of Fissure at a Later Stage after Extension of Infection into Joint.

Case 27.—Lieut. H., age 21. [*Ref. No.* 217.]

Lesion.—Comminuted shell fracture of femur 9 cm. from lower end. Fissure into knee-joint.

Clinical History.—Wounded Aug. 18, 1916. Incisions for drainage and removal of shell fragment at casualty clearing station, Aug. 19. Further incisions for drainage at base, Aug. 21. Much laceration of thigh muscles, with severe infection. Bubbles of gas in pus from wound. The knee-joint at first had the usual quiet effusion associated with fracture of the lower third of the femur.

The first complaint of pain in the knee was on the evening of Sept. 3. The following morning it was tender and hot, with increased effusion. Aspiration yielded a turbid fluid containing the streptococcus. Amputation, Sept. 4. Transferred to England, Sept. 17.

Examination of Limb, Sept. 4.—Femur: Periosteum thickened above and around fracture. Continuity of pus along main fissure from fracture to joint. Muscles: Abscess in crureus at level of amputation, communicating with fracture. Knee-joint: Early arthritis. Synovial membrane injected. Articular cartilage unaltered. (*Figs.* 239, 240, 241, 242.)

Table 18.—*Case* 27.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1 (soft bone)	In fissure	Streptococcus, staphylococcus, *B. coli*	+ (including *B. perfringens*)
,, 2	0·4 cm.	Streptococcus, staphylococcus, *B. coli*	0
,, 3	1·5 ,,	0	0
,, 4	4·1 ,,	0	0
Pus from wound at amputation	..	Streptococcus, staphylococcus, *B. coli*	0
Blood from vein at amputation	..	0	—

Exposure of bone to sepsis.—17 days.
Amputation.—9.30 p.m.
Bone in ice.—From 9.30 p.m. to 10.55 p.m.
First culture taken from bone.—11.30 p.m.
Last culture taken from bone.—12 midnight.
Order of cultures.—4, 3, 2, 1.

Table 19.—*Case* 27. Knee-joint.

Days after infliction of Wound	Effusion	Organism
7	Blood-stained, synovial	0
9	,, ..	0
17	Turbid yellow; very few pus cells; the turbidity due almost entirely to organisms	Streptococcus

Table 20.—*Case* 27. EXAMINATION OF DIRECT SMEARS.

POINT FROM WHICH TAKEN	CELLS	ORGANISM
Femur 1, in crack at level of section of condyles	Pus	Streptococcus
Marrow, 2·5 cm. above fracture	Excess of reds	0
,, 5 ,, ,, ,,	Fewer reds	0
,, 7·5 ,, ,, ,,	Normal marrow	0

Description of Figs. 239, 240, 241, 242.

FIG. 239.—*Case* 27. Lower half of femur removed by amputation for streptococcal arthritis of knee 17 days after injury. Longitudinal section of bone, with fissure opened out to show continuity of pus from fracture to articular cartilage. A, Fracture. A^1, Fissure extending to joint. Same femur as in *Figs.* 240, 241, 242.

FIG. 240.—*Case* 27. Lower fragment of fractured femur with fissure (A^1) into knee-joint.

FIG. 241.—*Case* 27. Femur shown in *Fig.* 240 from below. A^1, Continuation of fissure through articular cartilage.

FIG. 242.—*Case* 27. Transverse section through condyles of femur shown in *Fig.* 240. A^1, Fissure in bruised condyle. Removed by amputation 17 days after injury. Penetration 0·4 cm. from fissure. Shows lateral penetration from fissure at a distance from the main fracture.

V. CONCLUSIONS.

1. From the surface of a divided or fractured bone exposed to infection, bacteria may penetrate to the deeper parts.

2. In an untreated fracture, penetration is apparently unlimited.

3. If the dead bone on the surface of the fracture is removed early, penetration is much reduced, and may not occur at all.

4. Penetration, particularly of anaerobes, is greatly increased by reduction of the circulation through the injured bone.

5. Penetration is increased by obstruction to drainage, either of the bone or of the soft parts.

6. The order of frequency and power of penetration of the bacteria found is: (1) Streptococcus; (2) Staphylococcus; (3) Anaerobes; (4) *B. coli.*

7. The rate of penetration is at its maximum during the first few days.

8. In the material examined, no difference in reaction to penetration has been noted between cancellous bone and the marrow of the shaft.

9. Bruising—an invariable accompaniment of projectile fracture—does not appear to facilitate penetration if the surface layer of débris is removed and drainage established.

10. In a septic fissure, growth of bacteria is progressive, and may lead to infection of a distant part—for example, a joint. Dissemination of infection throughout a bone takes place by penetration from its walls.

We wish to express our appreciation of the valuable help afforded us by Major J. W. West, R.A.M.C., in obtaining some of the material; of the intelligent co-operation of Private W. A. Hume (now Second Lieutenant R.F.A.), and Sergeant A. F. Collett, R.A.M.C.; and also of the skilful illustrations in line and colour by Sergeant A. K. Maxwell, R.A.M.C., for whose assistance we are indebted to the Medical Research Committee.

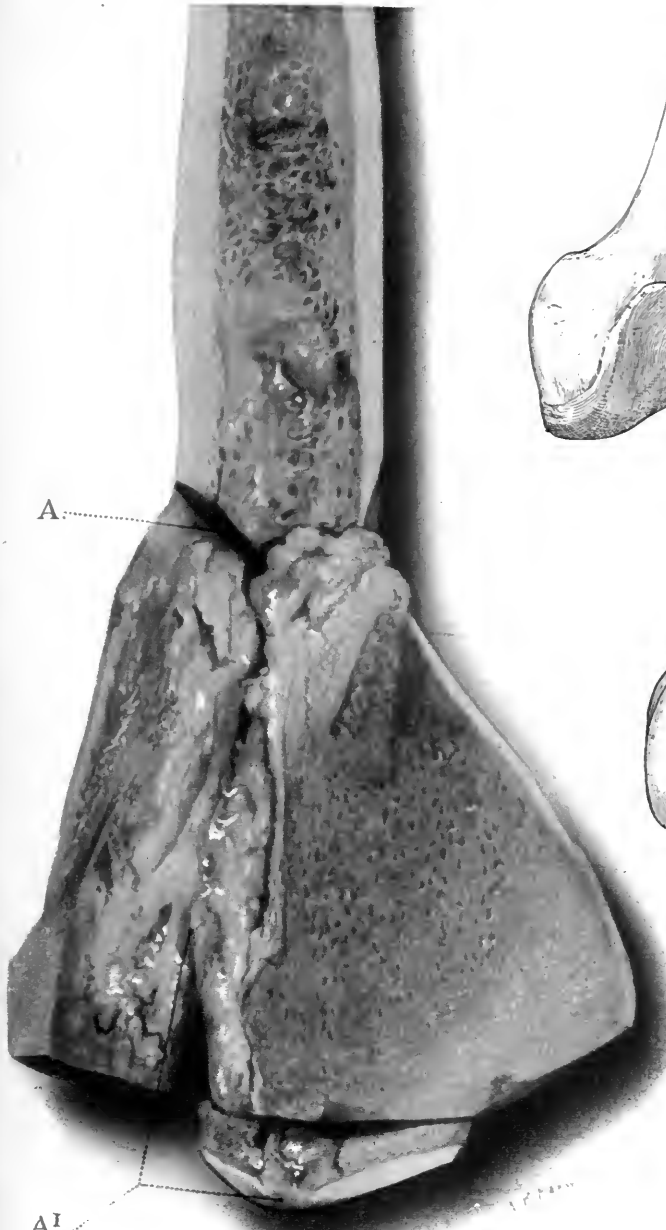


FIG. 239.

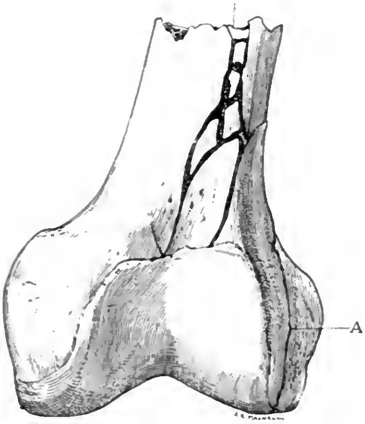


FIG. 240.

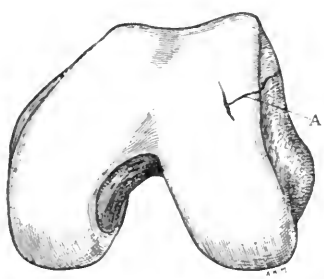


FIG. 241.

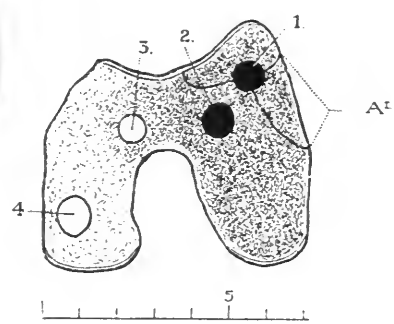


FIG. 242.

APPENDIX I.

SUMMARY OF CONTENTS.

Post-mortem growth in bone.—*Cases* 1, 2, 3.
Effect on penetration of the circulatory conditions preceding death.—*Cases* 4, 5.
Additional examples of penetration through normal bone.—*Cases* 6, 8.
Illustrations of the low penetrating power of *B. coli.*—*Cases* 9, 10.
Additional examples of extensive penetration associated with interruption of the medullary artery.—*Cases* 15, 16.
Additional examples illustrating early and late stages of penetration in untreated septic fracture.—*Cases* 18, 20.

Post-mortem Growth in Bone (*Cases* 1, 2, 3).—The importance of using fresh material is shown by the following observations. Three limbs, amputated in the lower third of the thigh for septic arthritis of the knee, were left for 21, 28, and 28½ hours respectively at room temperature in May, at the end of which time the femurs were examined for the presence of organisms. In all three the cut end of the femur was soiled by pus from the wound, and in *Cases* 2 and 3 this was the only opening by which organisms could enter the bone; in *Case* 1, owing to a fracture of the external condyle, the bone was open to infection at both ends. In *Cases* 1 and 2 growth was general throughout the bone, while in *Case* 3 the limit was fixed at about 11 cm. in 28½ hours.

Case 1.—Pte. R., age 26. Wounded April 24, 1916. Amputation 11.0 a.m. May 1. Examination of bone 2.30 p.m. May 2. Sepsis before amputation, 7 days. Duration of post-mortem growth, 28 hours.

Lesion.—Open septic knee-joint, with fracture and bruise of external condyle of femur (*Fig.* 243).

Table 21.—*Case* 1.

Specimen taken for Culture	Distance from Source of Infection	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	In fissure	Streptococcus, staphylococcus	0
,, 2	1·0 cm.	Streptococcus	0
,, 3	3·7 ,,	,,	0
,, 4	4·0 ,,	,,	0
,, 5	2·0 ,,	,,	0

Conclusion.—In 28 hours, growth to at least 5 cm.; limit not reached.

Case 2.—Pte. W. Wounded April 27, 1916. Amputation 6.0 p.m. May 2. Examination of bone 2.0 p.m. May 3. Sepsis before amputation, 5 days. Duration of post-mortem growth, 21 hours.

Lesion.—Open septic knee-joint, with bruise of external condyle of femur, but no fracture (*Fig.* 244.)

Table 22.—Case 2.

Specimen taken for Culture	Distance from Source of Infection	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	6·2 cm.	Streptococcus, *B. pyocyaneus*, *B. proteus*	0
,, 2	13·3 ,,	.. ..	+ (including *B. perfringens*)
,, 3	14·0 ,,	.. ..	+
,, 4	13·5 ,,	.. ..	—

Conclusion.—In 21 hours, growth to at least 10 cm.; limit not reached.

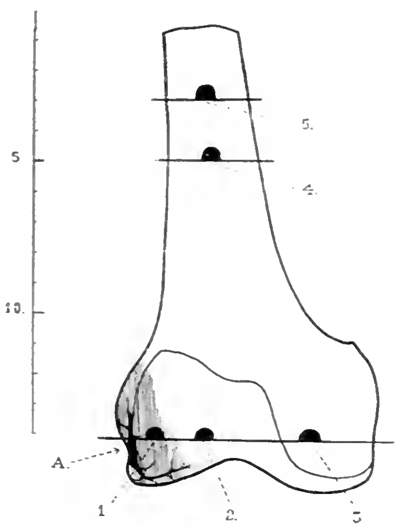


Fig. 243.

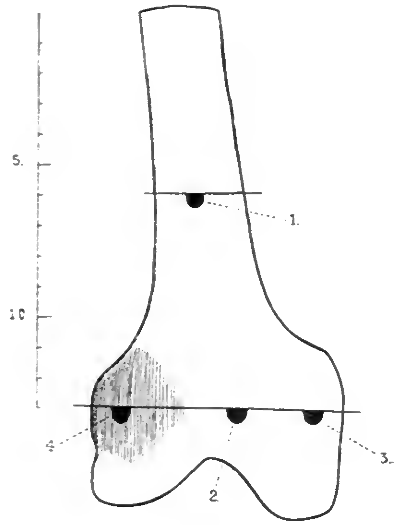


Fig. 244.

Fig. 243.—*Case* 1. Lower end of femur with fracture and bruise of external condyle. Cut surface soiled by pus from wound. Post-mortem growth from both ends in 28 hours at room temperature.

Fig. 244.—*Case* 2. Lower end of femur with bruise of external condyle, but no fracture. Cut surface soiled by pus from wound. Post-mortem growth from cut end to 10 cm. in 21 hours at room temperature.

Fig. 245.—*Case* 3. Lower end of femur with bruise of external condyle but no fracture. Cut end soiled by pus from wound. Post-mortem growth from cut end to 10 cm. in 28½ hours at room temperature.

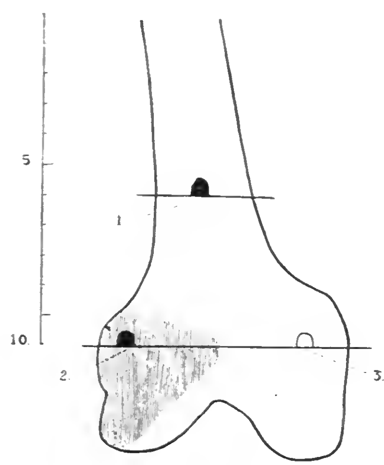


Fig. 245.

Case 3.—L.-Cpl. C. Date of wound not known. Amputation 11.0 a.m. May 5, 1916. Examination of bone 6.0 p.m. May 6. Sepsis before amputation: duration not known. Duration of post-mortem growth, 28½ hours.

Lesion.—Open septic knee-joint, with bruise of external condyle of femur, but no fracture (*Fig.* 245.)

Table 23.—*Case* 3.

Specimen taken for Culture	Distance from Source of Infection	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	5·3 cm.	Streptococcus	0
,, 2	11·0 ,,	0	0
,, 3	11·3 ,,	Streptococcus	0
Knee-joint	..	Streptococcus, staphylococcus	–

Conclusion.—In 28½ hours, growth to 10 cm.: limit reached (*Table* 23). Growth has extended further in the bruised than in the normal condyle, probably because the effused blood is a medium specially suited to the streptococcus.

These three bones show so extensive a penetration by organisms as to arouse suspicion of post-mortem growth. This suspicion has been confirmed by the results of examination of fresh material of corresponding type obtained by operation. Thus, the average distance of penetration of the streptococcus in fresh material has been found to be 2 cm., contrasting with an average distance of 8 cm. (limit not reached in two of the cases) for these three bones.

Effect on Penetration of the Circulatory Conditions Preceding Death (*Cases* 4, 5).

Case 4.—Lieut. B., age 21. Extensive saprophytic invasion of bone, associated with terminal circulatory failure.

Table 24.—*Case* 4.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1 ..	2·2 cm.	Streptococcus, *B. coli*	+
,, 2 ..	4·4 ,,	Streptococcus, mixed growth	+
,, 3 ..	6·7 ,,	Streptococcus, mixed growth	+
,, 4 ..	9·0 ,,	Mixed growth	+
,, 5 ..	14·0 ,,	,, ,,	+
,, 6 ..	18·8 ,,	Streptococcus, mixed growth	+
,, 7 ..	24·3 ,,	Streptococcus, staphylococcus, coliform bacilli	+
Blood culture 31 hours before death	..	0	0

Ante-mortem exposure of bone to sepsis.—10 days.
First culture taken from bone.—35 minutes after death.
Last culture taken from bone.—1 hour 25 minutes after death.
Order of cultures.—7, 6, 5, 4, 3, 2, 1.

Clinical History.—Wounded Sept. 19. 1916. Compound fracture of fibula. Amputation in lower third of thigh for gas gangrene at casualty clearing station. Sept. 19. Flaps stitched. Stitches removed at end of four days and pus evacuated. Gradual failure of circulation for three days before death, with frequent vomiting and sweats. Death 10.0 p.m. Sept. 29.

For the last forty-eight hours the extremities were cold and blue, and the radial pulse was absent, but patient was quite conscious. The stump was distended with extreme œdema and a moderate quantity of gas. There was no jaundice or local bronzing of the skin.

Clinical Picture.—Toxic failure of circulation. (*Figs.* 246, 247, and *Table* 24.)

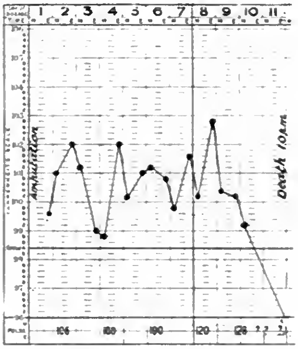


FIG. 246.—*Case* 4. Death from gas-gangrene toxæmia. Terminal failure of circulation.

Case 5.—Lieut. K., age 27. Absence of saprophytic invasion, associated with maintenance of the circulation till death.

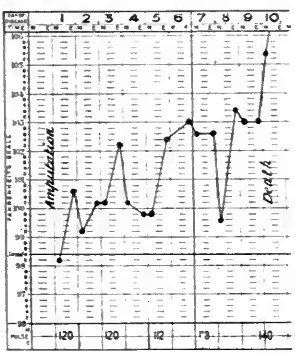


FIG. 248.

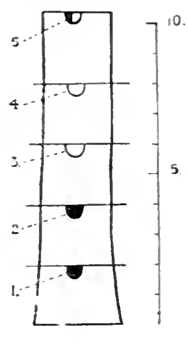


FIG. 249.

FIG. 248.—*Case* 5. Death from streptococcal septicæmia. Absence of terminal failure of circulation.

FIG. 249.—*Case* 5. 10 cm. of shaft of tibia from case dying of streptococcal septicæmia after amputation (A). Absence of any considerable penetration by organisms when circulation is maintained to the end. Growth at (5) of septicæmic origin.

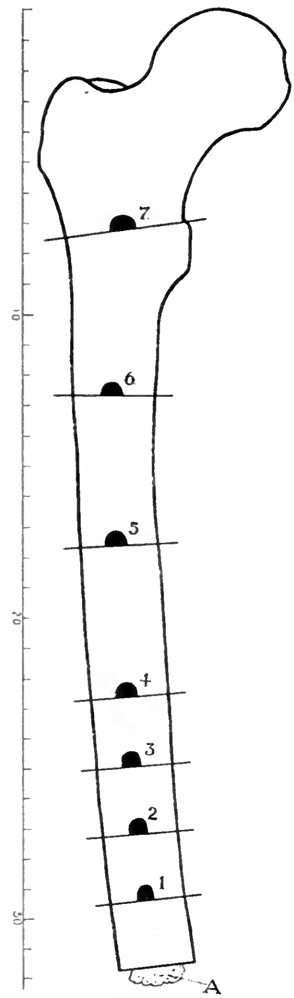


FIG. 247.—*Case* 4. Upper 32 cm. of femur from patient dying of gas gangrene after amputation. Penetration by organisms to 24 cm. accompanying terminal failure of circulation. A. Amputation.

Clinical History.—Wounded Feb. 8. 1917. Left foot shattered by shell. Amputation in lower third of leg. Feb. 9. Flaps stitched. Stitches removed after twenty-four hours. Œdema of leg up to knee. Death Feb. 18. 11.20 a.m.

Clinical Picture.—Septicæmia. (*Figs.* 248, 249, and *Table* 25.)

Table 25.—*Case* 5.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	1·5 cm.	Streptococcus, staphylococcus, *B. coli*	+
,, 2	3·5 ,,	Streptococcus, staphylococcus	0
,, 3	5·5 ,,	0	0
,, 4	7·5 ,,	0	0
,, 5	10·0 ,,	Streptococcus	0
Blood culture 18½ hours before death	..	,,	—

Ante-mortem exposure of bone to sepsis.—9 days.
Bone in ice.—From 11.50 a.m. to 5.45 p.m.
First culture taken from bone.—5.50 p.m.
Last culture taken from bone.—6.10 p.m.
Order of cultures.—5, 4, 3, 2, 1.

From a comparison of these two cases, it is seen that the condition of the peripheral circulation before death has an important bearing on the bacteriological findings. In *Case* 4, the prolonged failure of circulation which preceded somatic death is reflected in the temperature chart with its terminal fall, in the absence of radial pulse, in the anaerobic cellulitis of the stump, and in the extension of organisms throughout the whole length of the femur (see *Table* 24). The bone is, in fact, comparable in its absence of resistance to infection to *Cases* 1, 2, and 3, and the growth of organisms is in reality a post-mortem phenomenon occurring during life.

In *Case* 5, where death from streptococcal septicæmia was accompanied by a terminal rise of temperature and maintenance of the peripheral circulation up to the end, the circulatory conditions in the bone-marrow of the stump remained practically constant till death. In this bone, although the length of exposure to sepsis was the same as that of the previous case, organisms grew up only 4 cm. from the cut end (see *Table* 25). The growth at Section 5 is of septicæmic origin, while the absence of growth at Sections 3 and 4 can best be explained by the assumption that the septicæmia had not long been established.

In drawing deductions from observations on bones removed at autopsy, therefore, due consideration must be given to the clinical picture of the case before death. Material obtained at operation is free from this necessity for analysis, and conclusions may be drawn from it with greater directness and less error of interpretation. With the exception of the two bones just referred to, the whole of the material was obtained by operation.

Additional Examples of Penetration through Normal Bone (*Cases* 6, 8).

Case 6.—L.-Cpl. A. [*Ref. No.* 201.] Amputation through normal cancellous tissue.

Clinical History.—Wounded April 22, 1916. Flapless amputation 5 cm. below knee at casualty clearing station before April 26 (exact date not known). Upper end of fibula removed. Streptococcal infection of knee-joint through popliteus bursa. Re-amputation above knee at base, 12.30 p.m. May 12. (*Fig.* 250.)

Table 26.—*Case* 6.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA	DIRECT SMEAR
Tibia 1	0·5 cm.	Streptococcus, staphylococcus	0	0
„ 2	1·5 „	Streptococcus, staphylococcus	0	0
„ 3	4·0 „	0	0	0
Knee-joint	..	Streptococcus	0	Very few cocci
Femur, cancellous tissue (control)		0	0	
Femur, medulla (control)	..	0	0	

Exposure of bone to sepsis.—16 to 20 days.
First culture taken from bone.—2½ hours after amputation.
Last culture taken from bone.—3½ hours after amputation.
Order of cultures.—Femur. Tibia : 3, 1, 2.

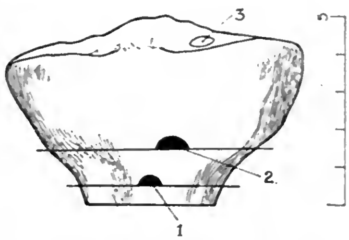


FIG. 250.—*Case* 6. Tibia from flapless amputation exposed to infection 16 to 20 days. Growth to 1·5 cm. from cut surface.

Case 8.—Lieut. M., age 23. [*Ref. No.* 203.]

Lesion.—Penetrating shell-wound of knee. Small fracture of articular surface of internal condyle of femur, with tear of semilunar cartilage. No injury to tibia.

Clinical History.—Wounded Aug. 22. 1916. Shell fragment removed at casualty clearing station Aug. 24. Arrived at base Aug. 27. Knee distended : aspiration —pus—streptococcus. Resection of knee-joint Aug. 28. Persistent œdema of leg. Amputation for sepsis Sept. 20, 2.35 p.m. Transferred to England Oct. 1.

Examination of Limb after Removal. Sept. 20.—Leg œdematous ; pus behind head of tibia : carious patch, not covered by granulations, on sawn surface of internal tibial tuberosity. No other pus collection in leg. (*Fig.* 251 and *Table* 27.)

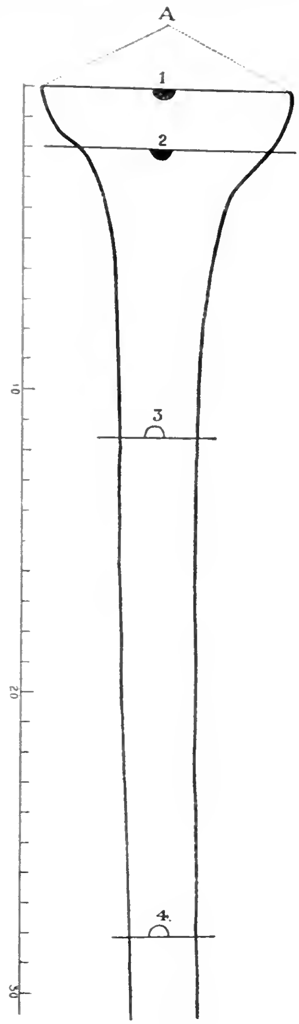


FIG. 251.

FIG. 251.—*Case* 8. Tibia removed by amputation 23 days after resection of knee-joint, showing penetration to 2 cm. in normal bone. (*Cf. Figs.* 250, 212, 214.)

Table 27.—Case 8.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	Surface	Streptococcus, staphylococcus	0
,, 2	2·0 cm.	Streptococcus	0
,, 3	11·2 ,,	0	0
,, 4	27·7 ,,	0	0
Femur 2 cm. from resected surface	..	Streptococcus	0
Pus from wound	..	Streptococcus, staphylococcus	0
Blood from vein at amputation	..	0	—

Exposure of bone to sepsis between resection and amputation.—23 days.
Bone in ice.—From 2.35 p.m. to 3.0 p.m.
First culture taken from bone.—3.0 p.m.
Last culture taken from bone.—4.0 p.m.
Order of cultures.—Tibia : 4, 3, 1, 2. Femur.

Note.—Tibia 2 is probably near the limit of penetration, because only the sample grown aerobically yielded streptococcus, whereas the anaerobic culture of tibia 1 grew streptococci and staphylococci.

Illustrations of Low Penetrating Power of B. Coli (*Cases* 9, 10).—In *Case* 9, well-drained bone was exposed in a septic flesh-wound into which a continuous feed of *B. coli* was maintained from the comminuted head of the fibula and the knee-joint. In *Case* 10, the fracture had originally been opened up, but the wound was allowed to close until drainage was reduced to that afforded by a narrow sinus.

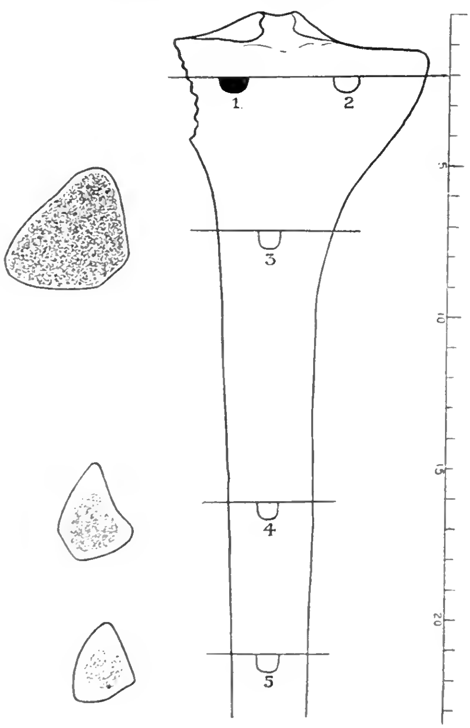


Fig. 252.

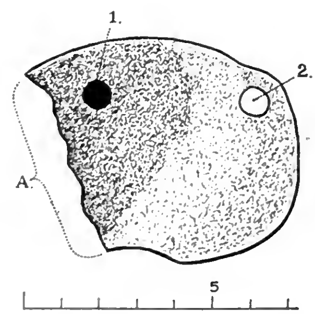


Fig. 253.

Fig. 252.—*Case* 9. Tibia removed by amputation 14 days after injury. Shell fracture of external tuberosity. Penetration of *B. coli* did not reach limits of bruise. Section 3 bruised.

Fig. 253.—*Case* 9. Transverse section of tibia shown in *Fig.* 252 at level of (1) and (2). A, Fracture.

Case 9.—Lieut. B., age 22. [*Ref. No*, 204.]

Lesion.—Compound fracture of head of fibula and external tuberosity of tibia by high-explosive shell.

Clinical History.—Wounded June 17, 1916, 9.0 p.m. No operation at casualty clearing station. First operation at base on admission, June 19, 10.30 p.m. Wound foul, with local gas infection of muscle. Wide resection, knee-joint open. Knee-joint aspirated June 26: pus, *B. coli*. Amputation above knee July 1, 2.45 p.m., for suppurative arthritis. Transferred to England July 21.

Examination of Limb, July 1.—Joint-fluid: viscid, yellow pus. Synovial membrane: thickened. Articular cartilage: soft and eroded. Tibia: bruised bone of external tuberosity, softened and grey on surface. (*Figs*. 252, 253.)

Table 28.—*Case* 9.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	0·8 cm.	*B. coli*	+ (including *B. perfringens*)
„ 2	4·7 „	0	0
„ 3	3·8 „	0	0
„ 4	12·3 „	0	0
„ 5	17·3 „	0	0
Femur (control)	..	0	0
Knee-joint, June 20 ..	..	0	0
„ June 26 ..	..	*B. coli*	0
„ July 1 ..	..	„	0
Blood from vein, July 6	..	0	—

Exposure of bone to sepsis before amputation.—14 days.
Tibia in ice.—From 2.45 p.m. to 6 p.m.
First culture taken from tibia.—6.20 p.m. Last culture.—6.45 p.m.
Order of cultures.—Tibia: 4, 2, 1, 3, 5.
Femur in ice.—From 2.45 p.m. to 7.40 p.m.
Culture taken from femur.—7.50 p.m., 1 cm. beneath erosion of articular cartilage.

Case 10.—Pte. L. [*Ref. No*. 205.]

Lesion.—Penetrating side-to-side high-explosive shell wound of outer aspect of knee-joint, with fracture of posterior part of external condyle of femur.

Table 29.—*Case* 10.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	0·5 cm.	*B. coli*	0
„ 2	1·8 „	0	0
„ 3	2·8 „	0	0
„ 4	3·8 „	0	0
„ 5	8·5 „	0	0
Tibia (control)	..	0	0
Knee-joint	..	*B. coli*, staphylococcus	0

Exposure of bone to sepsis.—21 days.
Amputation.—11 a.m.
Culture from joint.—2 p.m.
First culture taken from bone.—3.0 p.m. Last culture.—4.30 p.m.
Order of cultures.—Femur: 5, 4, 3, 2, 1. Tibia.

Clinical History.—Wounded April 26, 1916. Lateral incisions for drainage of septic knee on either side of patella. Original wound on outer side of joint enlarged and shell removed. Thomas knee-splint with strapping extension. Amputation for continued sepsis.

Examination of Limb, May 17, 2.0 p.m.—Lateral incisions for drainage granulating and no longer communicating with joint cavity. Moderate distention of knee by blood-stained fluid, which discharged through small sinus in centre of granulating original wound. Early erosion of articular cartilage. Synovial membrane intensely injected. No extracapsular extension of pus. Popliteal vessels intact. Tibia uninjured. (*Figs*. 254, 255, and *Table* 29.)

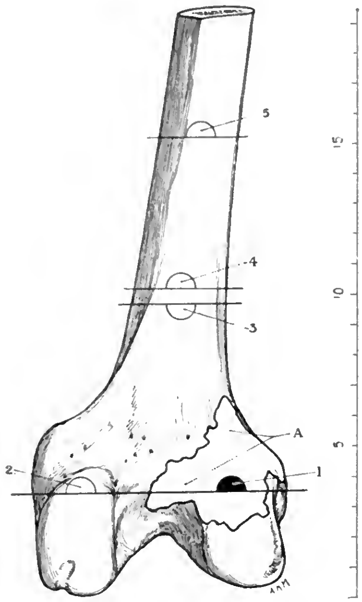


Fig. 254.

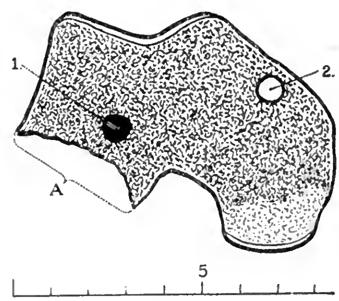


Fig. 255.

Fig. 254.—*Case* 10. Lower end of femur removed by amputation 21 days after injury. A, Foul wound of upper and back part of external condyle. Penetration slight, probably on account of nature of infection (*B. coli*).

Fig. 255.—*Case* 10. Transverse section of femur shown in *Fig*. 254 at level of (1) and (2).

Additional Examples of Extensive Penetration Associated with Interruption of the Medullary Artery (*Cases* 15, 16).

Case 15.—Capt. S., age 28.

Lesion.—Rifle-bullet fracture of middle of shaft of femur.

Table 30.—*Case* 15.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Upper fragment 5 ..	3·4 cm.	Streptococcus	0
Lower ,, 1 ..	In fissure	,,	+
,, ,, 2 ..	Limit of fissure	,,	+
,, ,, 3 ..	2·1 cm.	,,	+
,, ,, 4 ..	7·8	,,	+
Blood from vein, Nov. 9	..	..	0

Exposure of bone to sepsis.—42 days.
Bone in ice.—From 9.45 p.m. to 10.25 p.m.
First culture taken from bone.—10.40 p.m.
Last culture taken from bone.—11.0 p.m.
Order of cultures.—Lower fragment: 4, 3, 2, 1. Upper fragment: 5.

Clinical History.—Wounded Sept. 29, 1916. Left out thirty hours. Septic from commencement. Tube drainage established at casualty clearing station. Severe secondary hæmorrhage Nov. 9, forty-one days after original injury, when union was commencing. Blood transfusion, followed by amputation, Nov. 10, 9.45 p.m. Pneumonia. Death, Nov. 14.

Examination of Limb after Removal, Nov. 10.—Entry wound on outer side. Pocket of pus on inner side of femur beneath vastus internus. Hæmorrhage from small undetermined artery. Consolidation commencing in fracture; healthy-looking callus from bone ends. No appearance of inflammation of bone away from fracture.

Clinical Picture.—Septicæmia. (*Fig.* 256 and *Table* 30.)

The interpretation of *Case* 15 is complicated by the interval of twenty-four hours between the hæmorrhage and the amputation. It is conceivable that, in consequence of the diminution of the general circulation which followed the hæmorrhage, penetration of anaerobes was facilitated during this interval.

Case 16, although no opportunity of examining the upper fragment offered, is useful as a control on this point, since only forty-five minutes elapsed between secondary hæmorrhage and amputation. In other respects it is identical with *Case* 15.

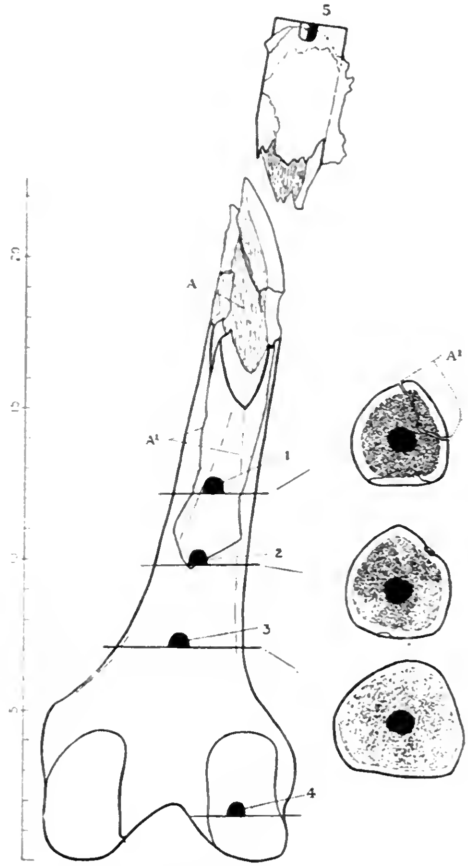


Fig. 256.—*Case* 15. Upper and lower fragments of fractured femur removed by amputation 42 days after injury and 24 hours after severe secondary hæmorrhage. Penetration of whole lower fragment by anaerobes associated with interruption of medullary artery.

Case 16.—Lieut. C., age 21.

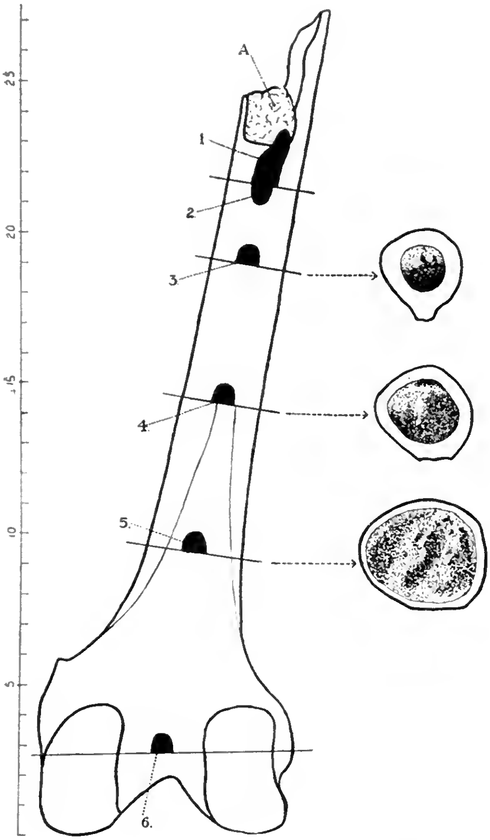
Lesion.—Compound comminuted fracture of shaft of femur.

Clinical History.—Perforating wound, just above middle of thigh, opened up at casualty clearing station. Condition on admission to base hospital Nov. 3, 1916, one of collapse. Severe secondary hæmorrhage Nov. 4, 10.0 a.m. Amputation Nov. 4, 10.30 a.m. Recurrence of hæmorrhage from stump. Death Nov. 6, 1.30 a.m.

Clinical Picture.—Septicæmia.

Examination of Limb after Removal, Nov. 4.—Muscle of limb normal in appearance except in immediate neighbourhood of fracture; no gas. (*Fig.* 257 and *Table* 31.)

In view of the similarity of the bacteriological findings in *Cases* 15 and 16, no stress can be laid on the possibilities of penetration being accentuated by loss of blood during the twenty-four hours which followed the hæmorrhage in



the former. From the nature of the cases it is difficult to draw any conclusion from them of the effects of secondary hæmorrhage. The bones can only be examined after either amputation or death. Amputation, if performed at all, is usually done immediately, and no opportunity occurs for any possible effects of the hæmorrhage to develop. If the bone were examined after death, such effects could not certainly be dissociated from those of the terminal failure of circulation.

FIG. 257.—*Case* 16. Lower fragment of femur removed by amputation 7 days after injury and immediately after severe secondary hæmorrhage. Penetration of whole lower fragment by anaerobes. Control on *Fig.* 256.

Table 31.—*Case* 16.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	Streptococcus	+ (including *B. perfringens*)
,, 2	1·3 cm.	,,	+ ,, ,,
,, 3	3·3 ,,	,,	+ ,, ,,
,, 4	8·0 ,,	,,	+ ,, ,,
,, 5	13·0 ,,	,,	+
,, 6	19·7 ,,	,,	+
Tibia, cancellous bone (control)	..	,,	0
Tibia, medulla of shaft (control)	..	,,	0
Blood from vein $1\frac{3}{4}$ hours after amputation	..	..	0

Exposure of bone to sepsis.—7 days.
Bone in ice.—From 11.10 a.m. to 2.30 p.m.
First culture taken from bone.—2.30 p.m.
Last culture taken from bone.—3.5 p.m.
Order of cultures.—Tibia: 1, 2. Femur: 6, 5, 4, 3, 2, 1.

Additional Examples Illustrating (1) Early, and (2) Late Stages of Penetration in Untreated Septic Fractures (*Cases* 18, 20).

1. Early Stage.

Case 18.—Lieut. O., age 23. [*Ref. No.* 209.]

Lesion.—Penetrating wound of external condyle of femur. High-explosive shell fragment and cloth embedded in cancellous bone.

Clinical History.—Wounded July 2, 1916. Severe multiple wounds by high-explosive shell. No surgical interference between infliction of wound and resection of knee-joint. Entry wound over most prominent part of condyle—i.e., very short track in soft parts.

Operation, July 5, 4.30 p.m.—Wound excised. External condyle cut away down to shell fragment. Subjacent bone black and foul-smelling, with crack into joint. Resection. Joint effusion: blood-stained, sterile. Transferred to England July 27.

Examination of Bone Removed, July 5.—External condyle deeply bruised, and separated from rest of bone by complete fissure. (*Figs.* 258, 259.)

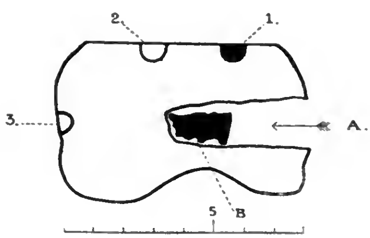


Fig. 258.

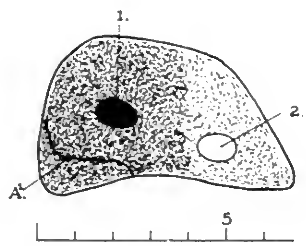


Fig. 259.

Fig. 258.—*Case* 18. Lowe extremity of femur removed by operation $3\frac{1}{2}$ days after injury (diagrammatic), showing shell fragment embedded, and penetration to 0·8 cm. by anaerobes.

Fig. 259.—*Case* 18. Tracing from upper surface of resected lower end of femur shown in *Fig.* 258, to show fissure, bruise, and degree of penetration in early untreated fracture.

Table 32.—*Case* 18.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	0·8 cm.	0	+
„ 2	1·9 „	0	0
„ 3	3·1 „	0	0
Knee-joint at operation	..	0	0

Exposure of bone to sepsis.—$3\frac{1}{2}$ days.
Resection.—4.30 p.m.
Bone in ice.—From 4.30 p.m. to 5.35 p.m.
First culture taken from bone.—6.0 p.m.
Last culture taken from bone.—6.40 p.m.
Order of cultures.—2, 1, 3.

2. Late Stage.

Case 20.—Pte. A. [*Ref. No.* 210.] Amputation in lower third of thigh for suppurative arthritis of knee.

Examination of Limb after Removal.—Vertical incision 5 inches long on either side of knee, opening joint and exposing condyles. Original shell-entry on inner side. Œdema of leg. No injury to tibia and fibula.

Bone: Foul débris *in situ*; fracture into joint; transverse pus-track between femur and subcrureal bursa, probably a tube track.

Knee-joint: Widely open: articular cartilage softened; synovial membrane sloughing: purulent effusion. Extracapsular extension of pus, commencing from popliteus bursa. (*Figs.* 260, 261.)

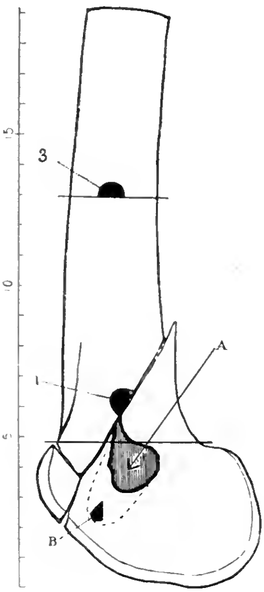


FIG. 260.

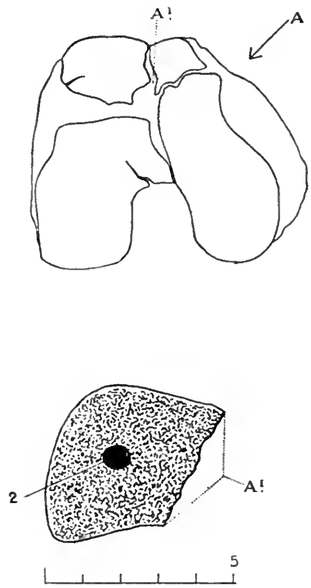


FIG. 261.

FIG. 260.—*Case* 20. Femur removed by amputation for shell fracture (A) of internal condyle. No surgical interference with actual fracture. Growth throughout bone.

FIG. 261.—*Case* 20. Femur shown in *Fig.* 260 from below to indicate fissure (A^1) separating internal condyle from rest of bone. Below is transverse section just above condyles to show penetration from fissure A^1.

Table 33.—*Case* 20.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	*B. coli*, staphylococcus	+ (including *B. perfringens*)
,, 2	1·5 cm.	Staphylococcus	0
,, 3	5·0 ,,	*B. coli*, streptococcus	0

Amputation.—12.30 p.m., June 28, 1916.
Limb in ice.—From 1 p.m. to 3.5 p.m.
First culture taken from bone.—4 p.m.
Last culture taken from bone.—4.30 p.m.
Order of cultures.—2, 1, 3.

APPENDIX II.

CULTURAL REACTIONS OF STAPHYLOCOCCI AND COLIFORM BACILLI ISOLATED FROM BONE.

Table 34.—SHOWING THE CULTURAL CHARACTERS OF TYPES OF *B. coli* ISOLATED FROM BONES.

SOURCE	TYPE	SACCHAROSE	DULCITE	GLUCOSE	MANNITE	LACTOSE	LITMUS MILK	GELATIN LIQUEFACTION	INDOL	MOTILITY
Case 24 : Tibia 1 (and knee-joint)	Group I	0	0	AG	AG	AG	AC	0	0	0
Lt. G. : Radius and humerus	,, II	0	AG	AG	AG	AG	A	0	+	+
Case 10 : Femur 1 (and knee-joint)	,, III	AG	AG	AG	AG	AG	AC	0	+	+
Case 19 : Tibia 1 (and knee-joint)	,, ,,	AG	AG	AG	AG	AG	A	0	+	0
Case 4 : Femur 1	,, ,,	AG	AG	AG	AG	AG	AC	0	+	+
Case 5 : Tibia 1	,, ,,	AG	AG	AG	AG	AG	AC	0	0	+
Case 20 : Femur 1 and 3	,, IV	AG	0	AG	AG	AG	AC	0	0	+
Case 27 : Femur 1	,, ,,	AG	0	AG	AG	AG	A	0	0	+

A = Acid. AG = Acid and gas. AC = Acid and clot. 0 = Absence of reaction.

Table 35. SHOWING THE DISTRIBUTION OF *B. coli* FROM A VARIETY OF SOURCES.

TYPE	BONE	SOIL	CESSPOOL SEWAGE	HUMAN FÆCES	HORSE, CALF, AND PIG FÆCES
Group I	1	2	4	62	9
,, II	1	0	1	49	33
,, III	4	10	1	61	68
,, IV	2	4	0	16	4

Note. The figures represent the actual number of strains isolated.

The cultural reactions of 20 strains of staphylococcus isolated from freshly-examined material have been tested as far as possible. Of these, 15 strains from 15 samples of bone, taken for culture from 8 patients, gave the following reactions: acidity in glucose, lactose, mannite, and saccharose; acidity and clot in milk; and liquefaction of gelatin. Five strains failed to liquefy gelatin, and two produced no acidity in mannite. None of the cultures showed any marked pigment production.

The cultural characteristics of a number of *B. coli* isolated from bones are arranged in *Table* 34, in the grouping suggested by MacConkey for the differentiation of coliform bacilli on the basis of their ability to ferment saccharose and dulcite.*

Utilizing the data of this writer for the distribution of the four types in various materials (*Table* 35), and having regard to the limited sampling in some of the cases, it appears that the figures are at least significant of the source of the *B. coli* cultivated from bones, since the closest correlation exists between these strains and those recovered from the soil.

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* A. T. MacConkey, "Further Observations on the Differentiation of Lactose-fermenting Bacilli, with special reference to those of Intestinal Origin," *Jour. of Hygiene*, ix, 86.

SHORT NOTES OF RARE OR OBSCURE CASES.

NOTE ON A CASE OF PEPTIC ULCER OPENING INTO THE TRANSVERSE COLON.

By GILBERT BARLING, Birmingham.

I performed gastrojejunostomy on a patient, age 54, in April, 1914. The symptoms of duodenal ulcer had existed for about four years previously, with intermissions. The pain came on two or three hours after food as a rule, but it might be continuous; it was often extremely troublesome at night. Vomiting had not occurred, and melena had not been observed. A rather acutely tender spot existed in the epigastrium a little above the mid-point between the umbilicus and the tip of the ensiform cartilage; there was also complaint of tenderness over the cæcum.

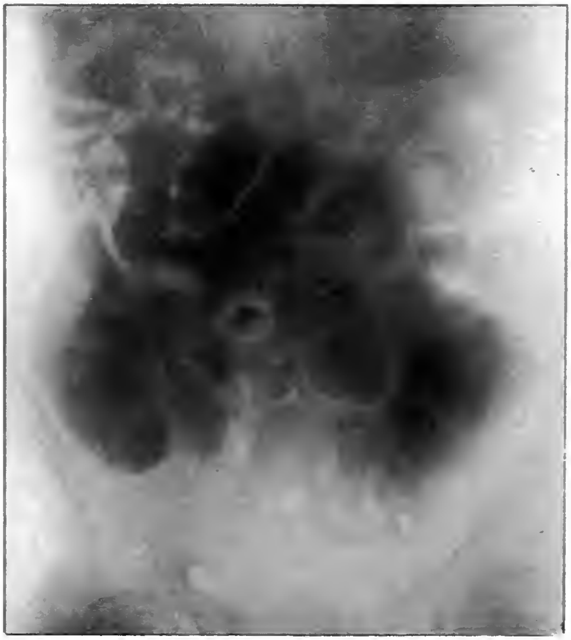

Fig. 262.—Skiagram showing communication between jejunum and transverse colon.

At the operation, the duodenum showed a cicatrix three-quarters of an inch beyond the pylorus; and extending from that point to the second portion of the duodenum was an ulcer of considerable extent, with a good deal of thickening around. A no-loop trans-mesocolic gastrojejunostomy was made. For the inner row of sutures catgut, and for the outer row thread, was employed; the pylorus was puckered with a purse-string suture; and the appendix, tied down by old adhesions, was removed, as was a band of old adhesion running from the apex of the gall-bladder towards the middle of the great omentum.

The patient made a good recovery, and was well until October, 1915, when he suffered a good deal of discomfort after food, this coming on after a period of overwork and exposure to chill. By rest, dieting, and alkalies this condition disappeared, but it created a suspicion at the time that the patient was suffering from a peptic ulcer near the point of anastomosis.

I did not see the patient again until February, 1917, when I was home on leave from France. I then learnt that in the summer of 1916 he went to work on the land, and about October suffered from severe abdominal pain and vomiting; the vomit was described as actually fæcal, and was associated with diarrhœa. The patient wasted rapidly, but although he was suffering from vomiting and diarrhœa, he was constantly hungry. For some time he took only fluid diet, but as his appetite was good, he was eventually put on solid food. This appeared to suit him better; vomiting disappeared, and the diarrhœa also, and at this time examination of the motions failed to detect undigested food. At varying intervals the vomiting and diarrhœa recurred, and later a phlebitis of the left femoral vein arose.

Fig. 263.—Skiagram showing communication between jejunum and transverse colon.

On examining the abdomen at this time (February), I could not detect any particular tenderness, but there was a general appearance of abdominal fullness, as though the intestinal tract were distended; the patient looked thin, but not ill. The diagnosis made at this time was that a communication existed between the stomach and colon or between the colon and jejunum, probably the latter. Operation was considered, but was not entertained, owing to the prospect that a very severe procedure would be required—probably excision of a portion of the colon, excision of the existing anastomosis, and a re-anastomosis.

I did not see the patient again until June 22, when I learnt that since my last interview he had had various ups and downs, sometimes taking solid food and having natural motions, at other times suffering from vomiting and diarrhœa. Wasting was rather extreme, and there was a curious patchy œdema about the patient, chiefly on the legs and abdominal wall, but there did not appear to be any dropsy of the abdomen. At this time I secured a radiographic report from Dr. Black, as follows :—

Radiographic Report.—A meal consisting of 12 oz. pudding, and containing 5 oz. barium sulphate, was eaten. This was watched as it passed into the stomach, and it was seen to pass directly through the gastrojejunostomy opening without any delay. The course of the meal was then difficult to follow. Part of it appeared to travel downwards on the left side in the line of the descending colon. It was not possible to say whether it was actually in the colon, or whether it was in dilated small intestine. Another part of the meal travelled to the right, apparently along the line of the transverse colon towards the hepatic flexure, and within ten minutes of eating the cæcum was seen to be filled.

Two prints of the negatives accompany this note (*Figs.* 262, 263), confirming the diagnosis of a communication between the stomach and colon or jejunum and colon.

In view of the patient's general condition, operation was not entertained, and the end came on July 6, 1917. Early that day the patient was seized with intense abdominal pain, and died the same evening. The diagnosis made was perforative peritonitis.

At the autopsy, there was general peritonitis, with a considerable amount of turbid fluid in the abdomen which arose from a leakage of an ulcer in the jejunum behind the transverse colon. Investigation of the parts involved showed that the junction of the stomach with the jejunum was a good one; the opening was two inches in diameter, and the margin perfectly sound. On the mesenteric border of the jejunum, immediately opposite the gastro-jejunostomy opening, there was an ulcer about five-eighths of an inch in diameter, but not very deep in most of its extent. The ulceration spreading from this had opened into the transverse colon, where there was a communication about half an inch in diameter between the jejunum and colon; the margins of this opening were perfectly healed and smooth.

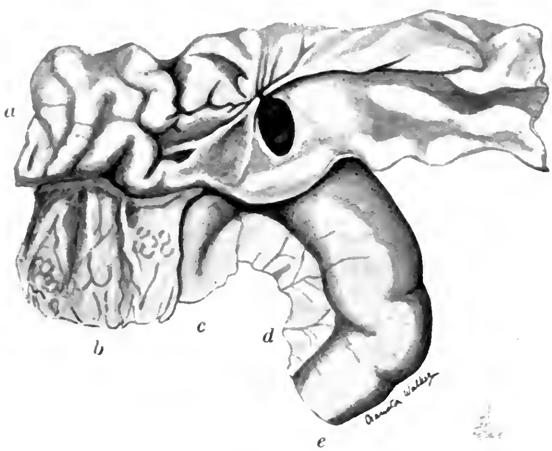

Fig. 264.—Showing the opening leading from the transverse colon into the jejunum. *a*. Transverse colon, laid open; *b*, Omentum; *c*, Duodenum; *d*, Mesentery; *e*, Jejunum.

The drawing (*Fig.* 264), for which I am indebted to Dr. Cranston Walker, shows the transverse colon laid open, with the healed peptic ulcer in the colic wall; the opening shown goes straight into the jejunum near the point of anastomosis with the stomach.

INSTRUCTIVE MISTAKES.

A COMPENSATION CASE, IN WHICH THE MARKINGS OF THE NUTRIENT CANALS OF THE ILIUM WERE MISTAKEN FOR FRACTURE: OF INTEREST FROM AN X-RAY POINT OF VIEW.

By Staff-Surgeon A. K. SMITH-SHAND, R.N.

B. P., age 29, shipwright, reported sick about the first week in March, 1915, in his ship, complaining of pain in the left gluteal region. This he attributed at the time to "getting his bedding wet" by sea-water. After twelve days' treatment he returned to full duty. Six weeks later he was confined

Fig. 265.—Skiagram similar to the one taken in the provincial hospital, showing only one arm of the V, which was mistaken for a fracture. (The arrows in *Figs.* 265, 266, and 267 point to the markings of the nutrient canals.)

to his hammock for ten days on account of the pain. From May till August he was again at full duty, until discharged to a naval hospital with similar symptoms. He remained under treatment in hospital till Nov. 22, when he was discharged to light duty. He again went sick in January, 1916, and after treatment in the same hospital, was finally invalided out of the Service

Fig. 266. — Showing characteristic V-shaped mark on the side of the alleged fracture.

Fig. 267. — Similar mark seen in ilium on side opposite to the alleged fracture.

on Feb. 4. The diagnosis of his condition was sciatica, and the Board of Survey made his case " not attributable to the Service."

Shortly after his discharge from the navy the man attended a provincial hospital, where he received treatment in the form of massage and exercises. He there stated that on Feb. 28, 1915, while in his ship, he fell down a forecastle ladder, bumping from step to step for a distance of twelve feet, but that no ill effects were noticed till a week later, when he reported sick, as seen above.

He was *x*-rayed at this provincial hospital, and reported to have a fracture of the ilium. On the strength of this report and of the history now given by the man, his case was taken up locally, and application for compensation for injury was made on his behalf to the Admiralty.

The medical department of the Admiralty caused investigation of his case to be undertaken. In addition to the note in the sick-bay records of his ship—that he attributed his pain to " getting his bedding wet "—his messmates and fellow-workers were cross-examined, and none of them could remember his having experienced, or having spoken of, the alleged fall down the ladder. The Admiralty then directed that he should be admitted to the R.N. Hospital, Chatham, for exhaustive investigation.

X-ray examination revealed that the line of fissure seen in the ilium was not a fracture, but was an abnormally large canal for a nutrient artery. There was no evidence of sacro-iliac disease. There was lateral curvature of the lumbar vertebræ to the right, but no evidence of caries of the spine, though there were slight signs of osteo-arthritis of the vertebræ in that region. Clinically this curvature was detected, and it was noted that there was also marked rigidity of the lumbar spine. The further past history was elicited that at the age of ten years he had an attack of typhoid fever, and this was followed by " trouble in his back," and subsequently by the formation of an abscess, which was opened ; the scar of this can still be seen. The case was therefore probably one of post-typhoid 'rigid spine,' and his pain was due to a sciatica in combination with the lumbar curvature and rigidity. The history of the case—showing that he walked about for a week after the alleged accident—precludes the question of fracture of the pelvis altogether.

Fig. 265 shows the line approaching the sacro-iliac joint which was mistaken for a fracture. *Fig.* 266, which takes in more of the body of the ilium, shows the characteristic V shape of the two nutrient canals joining; this made it evident that the case was not one of fracture. *Fig.* 267 is of the ilium on the other side of the same patient, and in it the marking is well evident.

The interest aroused by this case caused me to examine others, and *x*-ray negatives were taken of every suitable case that came to the *x*-ray room. In only a very few was a similar condition found in the ilium ; but in two or three the marking of the ilium was as noticeable as in the original case.

Further investigations were carried out ; a number of ilia were procured and *x*-rayed, and the marking was found to be practically constant, though showing numerous and marked differences in arrangement. The most common marking is that of a V-shaped appearance, situated on the body of the ilium close to the sacro-iliac synchondrosis, and this is practically the only one that

Fig. 268.—Skiagram of left ilium showing two main ventral canals (1, 2) and two main external canals (3, 4). (In *Figs.* 268–273, the solid lines in the diagrams indicate ventral canals, the dotted lines external canals.)

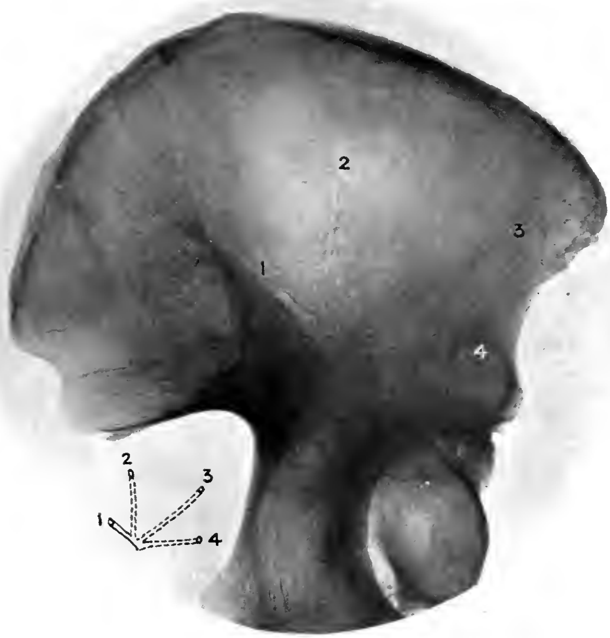

Fig. 269.—Skiagram of left ilium showing one main ventral canal (1) and three main external canals (2, 3, 4).

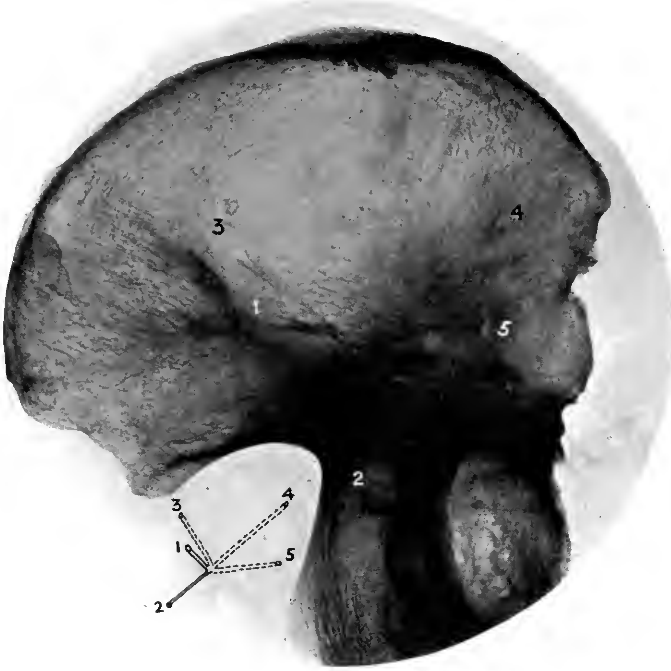

FIG. 270.—Skiagram of left ilium showing two main ventral canals (1, 2), one being in the sacro-sciatic notch, and three main external canals (3, 4, 5).

FIG. 271.—Skiagram of right ilium showing one main ventral canal (1) and four main external canals (2, 3, 4, 5).

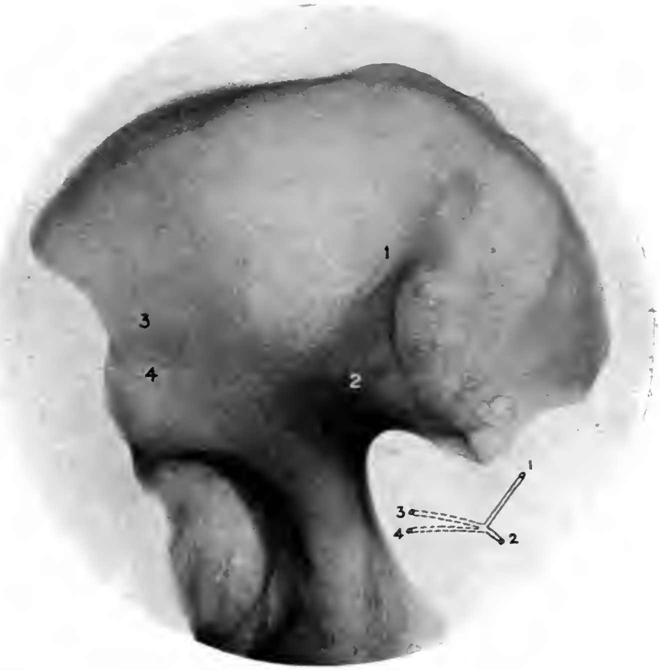

Fig. 272.—Skiagram of right ilium showing two main ventral canals (1, 2) and two main external canals (3, 4).

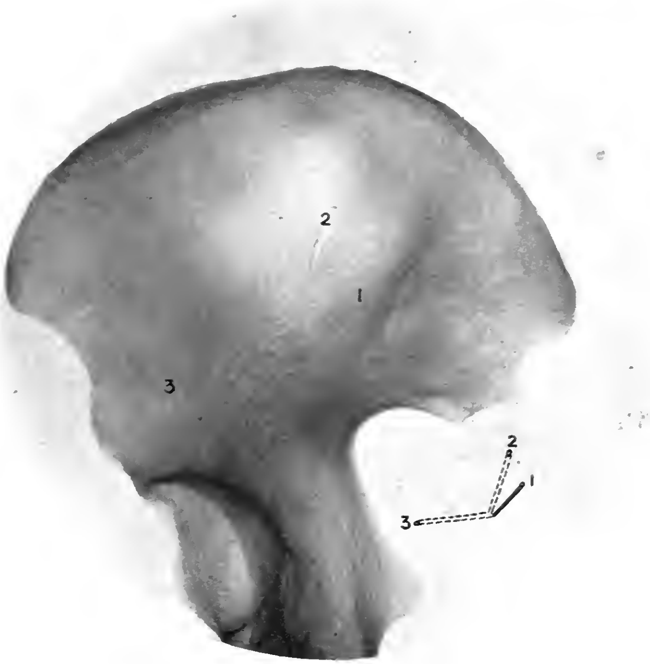

Fig. 273.—Skiagram of right ilium showing one very small ventral canal (1) and two main external canals (2, 3).

FIG. 274.—Skiagram of the ilium shown in *Fig.* 269 after injection with bismuth through the largest foramen. (1) Main ventral canal; (2, 3, 4) Main external canals.

FIG. 275.—Skiagram of ilium with the outer table sawn away to show the common meeting-point of the canals.

is apparent in the ilia x-rayed in the living subject. The V-shaped mark represents the canals for the nutrient arteries and their veins. The more central of the arms of the V is found to belong to the canal which gives ingress on the anterior or internal surface of the ilium to the nutrient artery derived from the iliolumbar artery, while the outer arm of the V represents that leading from the foramen on the posterior or external surface of the ilium which is supplied by the nutrient branch of the inferior gluteal artery. At the apex of the V these two separate arteries anastomose, and from that common point send off small branches to nourish the surrounding bone. This common point is situated in the thickest part of the ilium, just above the acetabulum, and above the sciatic notch, and it is reasonable to suppose that this is the true primary centre of the ossification of the ilium. This point of junction is practically constant.

On the other hand, the position and number of the foramina for the entrance of the nutrient arteries show a wide diversity. *On the internal surface of the ilium*, the commonest situation for the foramen appears to be at the lower part of the internal iliac fossa, close to the auricular portion of the ilium which articulates with the sacrum. This foramen is the only one of any size in about 50 per cent of the cases, but it may be double (see *Fig.* 268), or multiple, in which case the canals may be too small to be demonstrated by the x rays or by the passing of a bristle. Another position in which an additional or alternative foramen is found is just below the iliopectineal line, above the upper border of the great sacro-sciatic notch (see *Figs.* 270 and 272). This also invariably leads to the common point of anastomosis.

There were 200 ilia examined, and an analysis of the size, number, and position of the foramina in them brings out the following figures for the internal surface of the ilium: The foramina were *large* in 60 per cent, and of these 28 per cent were single, 32 per cent were multiple; they were *medium* in 33 per cent, and of these 6 per cent were single, 27 per cent were multiple; they were *small* in 7 per cent, all being multiple. In about 35 per cent the foramen in the sciatic notch was found—occasionally being the only one of any size on the inner surface of the ilium.

On the external surface of the ilium, there are two main positions for the foramina. The commonest is that mentioned in the text-books, viz., on the convex part of its surface, either just above or below the middle curved line. The other position is below the inferior curved line, close to and posterior to the anterior inferior spine. In each position the canals may be single or multiple, as may be seen in *Figs.* 268 to 273.

The analysis of the 200 ilia examined as above gives the following figures with regard to the external or posterior surface of the ilium: The foramina were *large* in 54 per cent, and of these 49 per cent were single, 5 per cent were multiple; they were *medium* in 20 per cent, and of these 13 per cent were single, 7 per cent were multiple; they were *small* in 26 per cent, all being multiple.

These figures show just what one would expect—namely, that if the canals are of large or medium size, the majority are single or few, whereas if they are small, the majority are multiple—the bone receiving its nourishment either by a few large or by many small arteries.

One of the ilia was injected with a bismuth emulsion, under pressure, into the largest foramen (*see Fig.* 274). The skiagram shows that not only are all the canals continuous through their common meeting-point, but also that small branches are given off in the course of the canals to supply the bone contiguous to them.

Fig. 275 shows an ilium which had the outer table sawn away and the canals laid bare to prove that the latter united at the common meeting-point.

The 200 ilia examined were from a collection in the Museum of the Royal College of Surgeons, which included bones, male and female, of all nationalities and periods, ranging from one of an Egyptian 3000 years B.C. to present-day British specimens. The pelves of gorillas and chimpanzees were also examined, and the canals were present, but appeared to be rather small.

To summarize, this case is of interest in demonstrating that it is possible to mistake an unusually large nutrient artery in the ilium for a fracture of that bone; further, it brings out the fact that the nutrient arteries of the ilium, whatever their point of entry, invariably converge to a common meeting-point, which may be considered the true primary centre of ossification of that bone.

In conclusion, I beg to express my sincere thanks to Professor Arthur Keith for his courteous help, and for the facilities afforded me for examining the specimens in the Museum.

REVIEWS AND NOTICES OF BOOKS.

Tumours, Innocent and Malignant: their Clinical Character and Appropriate Treatment. By Sir John Bland-Sutton, LL.D., F.R.C.S. With 380 illustrations. Sixth edition. 8vo. Pp. 790. 1917. London: Cassell & Co. Ltd. 21s. net.

This work has long held such a deservedly high place in medical literature that the appearance of the sixth edition after a life of nearly a quarter of a century is of much interest to the large circle of readers who use the book as their standard work of reference. In order to do any justice to the new edition it is necessary to study it carefully and compare it with the last edition, which appeared in 1911. It is then found that the author has not been content merely to add new material, although this has been done to the extent of upwards of one hundred pages, but that he has revised every paragraph with scrupulous care, expunging, modifying, and rearranging, so that the reader fails to find any evidence of the patchwork, and sometimes contradiction, which is apt to creep into new editions. The whole work has a refreshing appearance of youthful vigour about it, with evidence of careful discrimination in the selection of that which is new. The value of Bland-Sutton's *Tumours* has always been largely due to the author's intimate practical knowledge of comparative pathology, and in the new preface reference is very rightly made to the importance of this in an endeavour " to catch the deeper meaning of many tumours." No attempt is made to define the term 'tumour,' but it will be noticed that in the section dealing with cysts and pseudo-cysts the interpretation is made sufficiently wide to include such varying conditions as hydronephrosis, compound ganglion, and hydrocephalus. The reader would regret to lose any of the valuable information in this section, but in a future edition some reduction in this direction might make room for additional matter elsewhere. Of the new material, reference may especially be made to that dealing with the hypophysis—which is illustrated by several new figures—the pineal gland, the thymus gland, and the carotid body. Two new figures are added from a case in which a parathyroid tumour caused sudden death from pressure on the trachea. A useful addition will also be found in the remarks on primary cancer of the lung and bronchi.

The chapter dealing with the cause of cancer has been freely modified, and recent investigations receive due consideration. The author's own view is thus expressed " It (the cause) is most probably a microparasite which stimulates the normal epithelial cells of adult individuals to multiply and produce cancer in the same way that the male gamete or spermatozoon initiates reproductive changes in the female gamete or ovum." Let us hope that the author may live to know whether this view is correct or not.

Throughout the work Sir John Bland-Sutton does not hesitate to express his own opinion on any subject which is debatable, and it may be of interest to note what he has to say upon various matters taken almost at random.

In dealing with the subject of hypernephroma, reference is made to the doubt expressed by Stoerk and others as to the origin of these tumours of the kidney in adrenal rests, and the author shares the opinion that the majority of such tumours are carcinomas arising in the cells of the renal tubules.

It is satisfactory to find considerable scepticism expressed regarding the genuineness of most cases of supposed 'bronchogenous cancer,' and a new figure illustrates a case regarded as one of this nature in which the tumour of the neck proved to be secondary to a growth in the sinus pyriformis.

Most surgeons and pathologists will, we think, agree that, "although adenoma and carcinoma occasionally co-exist in the same breast, an adenoma never becomes transformed into a cancer"; but exception will be taken by many to the statement that "chronic mastitis is a precursor of adenomas as well as a precancerous condition."

In dealing with the subject of rodent ulcer, the author uses the term as synonymous with cancer of the sebaceous glands, but mentions the other views which are held as to the origin of the growth. The description of the histology of the growth is not altogether satisfactory, and the subject is one which seems deserving of at least one illustration.

It is well known that much difficulty is experienced in determining the real nature and origin of the so-called 'renal sarcoma' of infancy, and we must confess that the author's view that the epithelial cylinders in these tumours are due to the entanglement of uriniferous tubules, and that the striated spindles are derived from the muscle-tissue of the renal pelvis, is not quite convincing. Can *striated* spindles be derived from the *plain* muscle fibres in this situation, and how shall we explain the occasional presence of cartilage in tumours of this kind? It seems far more likely that the tumours in question are composite in structure, and that their origin must be sought in some early phase in the development of the part.

In the section dealing with tumours of the testicle, reference is made to Paget's classical case, described in 1855 as a malignant enchondroma, and the subsequent discovery in the tumour of columnar-celled epithelium by Kanthack and Pigg which led them to regard the growth as a carcinoma with cartilage in the matrix. The author might have continued the history of this tumour, by recording the more recent discovery by Nicholson of epithelial pearls in the growth, thus showing that it must be regarded as a teratoma.

The author's views with regard to carcinoma of the ovary and Fallopian tube are well known, and are summed up as follows: "Evidence derived from reports of cases, and my own experience of cancer of the Fallopian tube in which the post-operative histories have been obtained, support the opinion that cancer of the tube, like cancer of the ovary, is almost invariably secondary to a focus in the gastro-intestinal tract." The following practical advice is a natural outcome of this opinion: "In the course of an ovariotomy, if the surgeon encounters a solid or semi-solid ovarian tumour, especially if the tumours are bilateral, this suggests a thorough examination of the gastro-intestinal tract for a primary focus."

This short notice may seem altogether inadequate; but a general review of a work of such established reputation seems quite superfluous; it speaks for itself. The excellent wood engravings, of which eighty are new, and many apt quotations from the poets, help to make our satisfaction with the book particularly complete.

Cerebellar Abscess: Its Etiology, Pathology, Diagnosis, and Treatment. By Isidore Friesner, M.D., New York, and Alfred Braun, M.D., New York. Large 8vo. Pp. 186, with 10 plates and 16 illustrations. 1916. London: William Heinemann. 12/6 net.

This is a short book constituting an epitome of the writings of other people about the anatomy and physiology of the cerebellum in brief, and about cerebellar abscesses in detail. A discernment on the part of the reader that this is the purpose of the authors will leave him satisfied that the task has been well carried out. But should he entertain the hope that such fruits of personal experience are about to be offered as shall aid him to cope with the difficult problem of cerebellar abscess, a good deal of disappointment awaits him. A full description of the authors' experience of even one case would have enhanced the value of the book, whilst the experience of many cases would probably have re-adjusted their own perspective in epitomizing the writings of other people.

The diagnosis of the presence of a cerebellar abscess is a notoriously difficult problem, and few lesions are so elusive. This difficulty is not lessened by a mere recapitulation of every symptom and sign that may or may not be present, and by a laborious extraction of the relative percentages of signs 'present'

or 'absent' in the cases under review. Not even an exact knowledge of the age incidence and the sex frequency of the lesion (pp. 77, 78) is likely to lighten the burden of the surgeon who is confronted with the direct responsibility of the treatment of a case. Consequently, in the chapter on 'Symptoms' no clear impression is made upon the reader of the salient clinical features of a cerebellar abscess, neither is the impression left that a cerebellar abscess frequently has no salient clinical features at all. As a description of symptoms that may be due to any lesion of the cerebellum the chapter is of value, and contains a lucid analysis of Bárány's recent work on spontaneous deviation and induced nystagmus. But the authors fail to point out that these tests are of far more value in cases of cerebellar tumour, and that cases of cerebellar abscess are often far too ill to be submitted to the former one, and are frequently far too young to co-operate intelligently in its execution (they note that cerebellar abscesses are most common between the ages of ten and twenty years). As for induced nystagmus, it has long since lost its value as a precise diagnostic sign, on account of the extreme variability of its response. This aspect is fully developed under the heading 'Differential Diagnosis,' in the sub-section on labyrinthitis, which completely—but possibly unwittingly—discredits the value of the test.

In this same chapter a grave omission from the differential diagnosis of meningitis from cerebellar abscess is made. Meningitis is a very common disease and cerebellar abscess a comparatively rare one, so that one of the earliest and most reliable signs of meningitis ought to be familiar to everyone. *Irregularity of the pulse-rate* is established from the onset in meningitis—a feature of the disease to which Horsley attached the greatest importance, and he repeatedly emphasized its great diagnostic value in his writings. A failure to refer to this sign must be an oversight on the part of the authors. Their statement that "Hysteria may be mistaken for cerebellar abscess" must be accepted as possible, but we think that it would have been more helpful to the reader if it had not been suggested, whilst the inclusion of the differential diagnosis between cerebellar abscess and acute polioencephalitis of the cerebellum would have been a valuable substitute in its place.

The etiology of cerebellar abscess has been collected and analyzed with considerable care from groups of selected published cases, and the authors have done good service in calling attention to its intimate relationship to middle-ear disease. "Ninety-eight per cent of cerebellar abscesses are otitic in origin" is the opening sentence of their preface, and it is probably the most important one in the whole work. It might well be printed in capital letters, and repeated at intervals throughout the book, to indicate in what direction the successful treatment of cerebellar abscess lies. Nearly 90 per cent of those of otitic origin follow upon chronic suppuration of the ear, the small remainder being the sequel of acute suppuration. Now chronic suppuration of the middle ear is a preventible disease, and its existence on a large scale is merely the fruit of indifference to the remote sequels of oral sepsis improperly cared for. With the disappearance of chronic aural suppuration, cerebellar abscesses, with their difficult diagnosis and unsatisfactory treatment (the average death-rate of those operated upon is nearly 70 per cent !), will also disappear, and they may then take their place in the category of preventible diseases. 'Diagnosis' and 'Treatment' are the Dead Sea fruit of surgery when contrasted with the harvest of 'Prevention,' and if the authors' book should serve as a stimulus to thought in this direction, then they have written probably better than they knew.

La Chirurgia degli Organi di Movimento. Edited by Dr. V. Putti. Pp. 159, figures 19. Vol. I, fasc. 1. Price abroad, 35 lire.

This is the first number of a new journal, published in Bologna, and devoted to the surgery of the limbs, or orthopædic surgery, as it has become the custom to call it.

The editor, Dr. Putti, contributes the first and most interesting article, on the operative mobilization of ankylosis of the knee. His method consists in a very free exposure of the joint after division of the tubercle of the tibia and turning aside the patella, and then taking free flaps of fascia lata and covering the raw surfaces of the

femur and tibia. The tendon of the quadriceps is lengthened after a Z-shaped incision. He gives details of six cases, in which all except one acquired from sixty to ninety degrees of movement. The main criticism about this procedure is, that if the bone ends are so widely exposed as to permit of their being enveloped in fascia, this can only be secured by a complete sacrifice of the lateral and crucial ligaments, the absence of which must endanger the stability of the limb.

Other articles are contributed by Dr. Vanghetti on plastic amputation stumps, and by Dr. Delitala on the normal and pathological anatomy of the tarsus in relation to traumatic lesions. Dr. Serra describes some very interesting cases of the transplantation of bone in the human subject, in which he had the opportunity of examining microscopically the grafted area at varying periods after the operation. The pictures of the microscopical preparations are exceedingly clear, and afford a demonstration of the active vitality of the grafted tissue.

The whole publication is well printed and splendidly illustrated, and represents a very real addition to the current literature of orthopædic surgery.

Common Diseases of the Male Urethra. By Frank Kidd, F.R.C.S. 8vo. Pp. 132, with numerous illustrations. 1917. London: Longmans, Green & Co. 5/- net.

This small book is an essentially practical one, dealing with the diagnosis and cure of gonorrhœa and its principal complications in the male. Its chief value consists in the precise directions given as to examination, instrumentation, and the use of irrigation. It is a practical outcome of the study of the "pathology of the living." A valuable feature of the work consists in brief notes of seventy cases illustrating special points of exceptional interest in etiology and treatment.

Notes on Military Orthopædics. By Col. Sir Robert Jones, C.B. 8vo. Pp. 132, 128 illustrations. 1917. London: For the Red Cross Society, Cassell & Co. Ltd. 2/6 net.

This work, which bears an introductory note by Sir Alfred Keogh urging the importance of orthopædic surgery for the military medical officer, is an attempt to present the general principles of limb surgery in a condensed, authoritative, and clear manner. It is an *ex cathedra* statement in the best sense of the term, that is to say, it is an expression of the clear convictions of its author derived from his own unrivalled experience, and it does not attempt to discuss or deal with conflicting or divergent views. It may be doubted whether the methods which have proved invaluable in the treatment of deformities of children are equally well adapted for application to gunshot injuries. This criticism is particularly apposite in considering the use of the abduction frame for the treatment of high fractures of the femur. The sections dealing with the deformities of the feet and disabilities of the knee-joint are the most valuable in the book, whilst those relating to the treatment of fractures are most open to criticism, on the ground that they do not sufficiently recognize the many difficulties and complications of the subject, and the need for a correspondingly varied technique in treatment.

Medical and Surgical Reports of the Episcopal Hospital, Philadelphia. Vol. III. Pp. 356, 124 illustrations. 1915. Philadelphia: Wm. J. Dornan.

We heartily congratulate the editor of this volume, Dr. Ashley Ashhurst, on the energy and enterprise which brought together such a large number of valuable papers from the workers of a single hospital during one year. As most of the papers have already appeared elsewhere, usually in one of the American periodicals, it is not necessary to mention them in detail. The most notable contents of the present volume are the articles on modern bone and joint surgery, many of which are by Dr. Ashhurst himself, and those on the diseases of the eye by Dr. Oram Ring.

THOMAS VICARY.

1490–1562.

Thomas Vicary, by virtue of his age and position, was leader of the band of surgeons who desired their calling advanced to a better position under the Tudor dynasty. He seems to have gained his influence by his personality more than by his writings. In this respect he differed from Gale and Clowes, who were rough and pushing; from Halle, who was active as a satirist and persecutor of quacks; from Banister, a polished gentleman; and from Read, who died too young to do more than lend the energy of youth to the movement in which all were interested.

The facts of Vicary's life are few, but they have been diligently gleaned by Dr. J. F. Furnivall and by Dr. Norman Moore.

He was probably born in Kent at some time between the years 1490 and 1500, as the first notice of him occurs in Manningham's Diary, where he is stated to have been "at first a meane practiser in Maidstone until the King advanced him for curing his sore legge."

In London he was admitted to the Barbers' Company, where he rose rapidly until he became Master in 1530. In 1540 the Company of Barbers was united with the Guild of Surgeons to form the United Company of Barber Surgeons. This union lasted until 1745, when it was dissolved, the Barbers' Company continuing, as it does to this day, on the original site in Monkwell Street, whilst the Surgeons built themselves a new Hall in the Old Bailey. Vicary was nominated the first Master of the United Company, and he was re-elected to the Mastership in 1546, in 1548, and in 1557, a proof of the high esteem in which he was held by his contemporaries, for no one after him was ever chosen so often.

In 1528 he was appointed surgeon to King Henry VIII, and two years later he was granted a reversion of the places, held by Marcellus de la More, of Serjeant Surgeon and chief Surgeon to the King. The reversion fell in during the year 1535. Vicary retained the post until his death in 1561, and thus served under Henry VIII, Edward VI, Mary, and Elizabeth.

Like the Court servants of the time, but to a lesser degree, he was rewarded by grants of confiscated church property. In 1539 he obtained the beneficial lease for twenty-one years of the rectory house and tithes of the recently dissolved Boxley Abbey in Kent. The Abbey had been celebrated for its miraculous rood, with eyes stirring like a living thing, its body bowing, its forehead frowning, and its lower lip moving as if about to speak. In 1541 he bought additional lands at Boxley from Sir Thomas Wyatt, the poet, and in 1542 he was appointed with his son, William, a Bailiff of Boxley Manor, with an annuity of £10 a year. In 1557 he was rich enough to lend money to the United Company when it had got into financial difficulties, and

there is a minute that "Mr. Thomas Vicary shal paye and discharge the debtes of the howse and shal haue the plate of the Crafte in pawne or pledge untyl suche tyme as the sayde summe of monnie bee unto hym payde agyne." In the following year he lent £100 to his brother-in-law, Thomas Dunkyn, yeoman, of Shoreditch, and about the same time he bought a house and some land next to Boxley Church.

In 1548, after the confiscation of the Hospital by Henry VIII, the citizens of London determined to re-endow St. Bartholomew's Hospital at their own cost, and Vicary was appointed a governor, with three surgeons under him, William Cartar, Thomas Bailey, and George Vaughan. He must have carried out his duties to the satisfaction of the Mayor and his brethren the Aldermen, because in 1552 he was chosen "one of the assistaunts of this howse for the term of his life," a position rarely, if ever again, bestowed upon an active member of the staff. He lived in the Hospital, was assigned the old conventual garden for his use, and probably carried out the same duties that had been performed by the Master of the Hospital in pre-reformation times.

He married twice: (1) The sister of Thomas Dunkyn, by whom he had a son, William, who lived to manhood, was probably a surgeon, but died before his father; and (2) Alice Bucke, whom he married in 1547. She survived him, and inherited most of his property.

Vicary's will is dated January 27, 1560–1, and was proved on April 7, 1562, so that he probably died about the end of the year 1561. He bequeathed his best gown to Robert Balthrop, whose monument is behind the organ in the church of St. Bartholomew-the-Less; his second-best gown to Thomas Bayly; his gown faced with black satin to Robert Muddesley; his best cloke guarded with velvet to George Bucke; his doublet of crimson satin to George Vaughan, with other little mementoes, which show that he was on terms of friendship with his colleagues. To the United Company itself he bequeathed his copy of "Gui de chauliac, ii billes, ii bowes; ii sheafs of arrows; ii braces or arm-guards; ii shooting gloves; ii skulls; one hand gun and one jack or quilted coat."

Vicary is best known as the author of *A profitable Treatise of the Anatomie of Man's body*, which is generally quoted by the short title of the later editions as *The Englishman's Treasure.* The earliest known edition is that of 1577. It is dedicated to Sir Rouland Hayward, the president, and the governors, by William Clowes, William Beton, Richard Story, and Edward Bayly, then surgeons to St. Bartholomew's Hospital.

There has been some question as to the real authorship of this work. The ate Dr. F. J. Payne showed conclusively that it is taken mainly from an unknown author, writing in English not later than the fourteenth century, who based his work upon Lanfrank and Mondeville. The unfinished manuscript of this work was actually in the possession of Dr. Payne, who gives two theories: "(1) Vicary was in possession of a copy of this treatise, of which he made an abridgement, using the same words—sometimes not understanding them—and brought it out as his own. One does not like to think of Vicary as an actual literary impostor, and there is perhaps another supposition; (2) Possibly Vicary did not profess to be the author. The only absolutely known printed edition

THOMAS VICARY.

From a crayon enlargement by A. T. Young, in the possession of D'Arcy Power, F.S.A.

was brought out fifteen years after his death by his colleagues at St. Bartholomew's Hospital, and they may have found a manuscript tract which they regarded as Vicary's—though he never laid claim to it—and published it as his." John Halle, a contemporary and friend of Vicary, however, makes the following statement in the prologue to his " very frutefull and necessary briefe worke of Anatomie," printed in 1565—that he was somewhat encouraged to publish it " by the example of good Maister Vicarie, late sargeante chyrurgien to the queenes highnes ; Who was the firste that euer wrote a treatyse of Anatomie in Englyshe (to the profite of his brethren chirurgiens and the helpe of younge studentes) so farre as I can learne." Vicary's treatise, therefore, was known as early as 1565, and it is stated that a transcript in manuscript was made from an edition supposed to have been published in 1548, although no such edition is now known to exist. The most plausible explanation appears to be that Vicary edited the fourteenth century author in exactly the same way as Halle states that he himself edited Lanfrank—that is, he borrowed various manuscripts, compared them diligently, omitting some things, adding others, and then allowed his finished labours to be circulated in manuscript in much the same way that Sir Thomas Browne permitted the *Religio Medici* to be circulated a hundred years later. The prestige of Vicary's name made it worth while in 1577 for his colleagues to print from one of the manuscripts, and the result was so successful that a book, which was in reality worthless, was reprinted in 1580, 1586, 1613, 1626, 1633, and 1641, which shows the low standard of anatomical knowledge ruling amongst Barber Surgeons in the sixteenth century.

Before dealing with anatomy proper, Vicary enumerates the accidents and qualities required in a good surgeon as they had been handed down from time immemorial and had gradually become standardized. "All Authors doe agree that a Chirurgion shoulde bee chosen by his complexion and that his complexion bee verie temperate and all his members well proportioned. For Rasis sayeth Whose face is not seemely it is unpossible for him to have good manners. And principally it is necessarie that he bee a good liver and a keeper of the holye commaundements of God, of whome commeth all cunning and grace, and that his bodye bee not quaking, and his handes stedfast, his fingers long and small and not tremblinge ; and that his left hande be as readie as his right hande with al his lymmes able to fulfil the good workes of the soule. And I doo note four thinges moste specially that every Chirurgion ought to have. The first that he be learned ; the seconde that he be expert ; the thirde that he be ingenious ; the fourth that he be well mannered. The firste (I sayde) he ought to be learned and that he knowe his principles not only in Chirurgery but also in Physicke that he may the better defende his Surgery. Also he ought to be seene in Naturall Philosophie and in Grammar, that he speake congruitie in Logike. Also he must knowe the Anatomie ; for all Authors write against those Surgeons that worke in mans body, not knowing the Anatomie ; for they bee likened to a blinde man that cutteth in a vine tree for he taketh more or less than he ought to doe. The seconde, I sayde, he must be expert, for he ought to knowe and to see other mens work and after to have use and exercise. He ought also to be ingenious or wittie for all thinges belonging to Chirurgerie

may not be written nor with letters set foorth. He must be wel mannered and that he have all these good conditions here folowing; First, that he be no spous-breaker nor no drunkard. For the Philosphers saye amongst all other thinges beware of those persons that followe drunkenness, for they be accompted for no men because they live a life bestiall. Likewise a Chirurgion must take heede that hee deceive no man with his vaine promises for to make of a smal matter a great, because he would be counted the more famous. And amongest other thinges they maye neither be flatterers, nor mockers nor privie backbyters of other men. They must be as privie and as secret as any Confessour of al thinges that they shal eyther heare or see in the house of their Pacient. Also they shoulde doe their diligence as wel to the poore as to the riche. They shal never discomfort their patient and shal commaunde all that bee about him that they doe the same, but to his friendes speake truthe, as the case standeth. They must also be bold in those things whereof they be certaine and as dreadfull in all perilles. They may not chide with the sicke but be alwayes pleasaunt and merie. They must not covet any woman by waye of vylanie and specially in the house of their Pacient. They shal not for covetousnesse of money take in hande those cures that be uncurable, nor never set any certaine day of the sickeman's health for it lyeth not in their power. They must also be gracious and good to the poore and of the riche take liberally for bothe. And see they never prayse themselves for that redoundeth more to their shame and discredite than to their fame and worship. For a cunning and skilful Chirurgion neede never vaunte of his dooings for his workes wyll ever get credite ynough. Likewise that they despise no other Chirurgion without a great cause, for it is meete that one chirurgion should love another as Christe loveth us all. And in thus dooing they shall increase both in vertue and cunning to the honour of God and worldly fame. To whome he bring us all. Amen! Heereafter foloweth the Anathommie."

The portrait of Vicary which illustrates this account of him is a careful enlargement by Mr. A. T. Young of the figure in Holbein's picture which still hangs in the Barbers' Hall in Monkwell Street. It was painted about 1545 to commemorate the Union of the Barbers and Surgeons, and is therefore a faithful likeness of Vicary. He is represented in his Master's gown, with the usual head covering which was worn under the hat or cap, as may be seen in the portrait of John Halle, p. 182 of this Journal.

GUNSHOT WOUNDS OF THE CHEST.

By P. T. CRYMBLE, Belfast.

The following paper is based on fifteen months' work in a base hospital in France and twelve months' in a similar hospital at home. In France the cases were usually seen in from one to seven days from the time of being wounded, and the *x*-ray examination was made with the object of determining the condition of the thorax and of estimating the progress of the case. At home the examination was made as a preliminary to the removal of a foreign body. Many of the skiagrams were shown at a demonstration before the Etaples Medical Society in March, 1916, but since then the material has increased in amount, and one has had the experience of the later results.

In all cases the usual physical examination was made at the time of the *x*-ray examination, in order that the skiagram might be correlated with the physical signs. The *x*-ray examination was repeated in many cases, so that records were obtained of the various stages in the progress of the condition. The author is greatly indebted to his colleagues on the staff of the hospital, without whose co-operation the material could never have been obtained; and his thanks are due to Corporal Lounds for his great assistance in the *x*-ray examination, and to Corporal Waterhouse for the skill and enthusiasm with which he produced the records.

Material upon which the Paper is Based.

Hæmothorax	59	cases
Hæmopneumothorax	19	,,
Traumatic infarct	15	,,
Lung collapse	15	,,
Pyopneumothorax	8	,,
Pneumothorax	7	,,
Subphrenic abscess	4	,,
Various	30	,,
Localization of foreign bodies	54	,,
Total cases	211	

Apparatus.—In France a Butt outfit with a 16-inch coil was used. Power was obtained from a 15 H.P. oil engine which worked a dynamo producing a continuous current at 220 volts. Using the mercury interrupter, one obtained 2 to 4 milliampères in the secondary circuit. The unipolar electrolytic break gave up to 10 milliampères in the secondary circuit, but it frequently stopped working in the middle of the exposure, and was not used. An accelerator screen was employed, and a five-second exposure gave a good result, so that the skiagram could be obtained whilst the patient held his breath. The vertical screening stand was indispensable, and enabled one to carry out the examination with very little disturbance to the patient. It was

fitted with a stereoscopic shift, and as a rule the anticathode was about 22 inches from the plate.

Reduced prints were made of the 15 × 12 in. negatives, and the accompanying illustrations have been made from these prints. Unless otherwise stated, the rays have passed dorso-ventrally to the plate, which was in contact with the anterior chest wall. The right side of the chest is on the left side of the picture.

The Diaphragm.—The movements, shape, and position of the diaphragm usually show some alteration in wounds of the chest, and inspection of the two cupolæ of the diaphragm on the fluorescent screen is one of the most important parts of the *x*-ray examination of the chest.

The right cupola, bounded above by the clear lung area and below by the opaque liver, is not to be distinguished from the general abdominal opacity except in the presence of a right subphrenic gas-bubble. Superiorly the cardiac shadow blends with it, and makes an angle (cardio-hepatic angle) of almost ninety degrees slightly to the right of the vertebral column.

The left cupola is normally defined by the gastric gas-bubble. Superiorly it is overlapped to a considerable extent by the heart, and lateral to the heart the left lung area defines it.

Immobility or Deficient Movement of the Diaphragm.—This usually follows a perforating wound of the thorax, the diaphragmatic cupola on the injured side being affected. Frequently there is complete immobility, but in wounds of the lung apex only slight deficiency may be noticeable. It is also an accompaniment of lung collapse, being found on the same side as the collapse.

Comparison with the sound side of the chest will usually enable one to detect the defective movement, but the presence of any large supra-diaphragmatic lung area opacity may render the diaphragm invisible and prevent the observation being made. If the opacity be due to fluid in the pleural cavity, the diaphragm may be visible in the lying position. On the left side the presence of a stomach gas-bubble will enable one to note the position and movement of the diaphragm where the left lung area is opaque.

What is the explanation of this defective movement ? Is it a protective reflex fixation of the diaphragm in the position of expiration, or is it the result of deficient air entry into the injured lung ? The former explanation would seem to account for those cases where the lung area above the immobile diaphragm is clear and there is no evidence of any obstruction of the air entry into the lung. *Case* 14, recorded in ***Fig.*** 307, is an example of this condition. On the other hand, it would seem probable that if a lung is unable to expand owing to the presence of fluid in the pleural cavity or to laceration of its substance or to obstruction of its bronchi, then during the inspiratory enlargement of the thoracic cage, the diaphragm will be drawn upwards and the mediastinum will be drawn towards the affected side. This retraction of the mediastinum and diaphragm towards an opaque lung area is best seen in lung collapse (***Fig.*** 296), and the diaphragmatic elevation is also an accompaniment of hæmothorax.

Adhesions between the costal and diaphragmatic pleura, or between the visceral and diaphragmatic pleura, will cause permanent defective movement and marked alteration in the shape of the cupola during inspiration.

Shape and Position of the Diaphragm.—The right cupola of the diaphragm normally occupies a higher position than the left, and it shows occasionally some irregularity of outline, due possibly to the shape of the underlying liver. The left cupola has a regular curved outline, and may surmount a stomach gas-bubble or stomach and colon gas-bubbles. During inspiration very little alteration in the shape of the diaphragmatic outline takes place. There is simply a descent of the abdominal contents without a flattening out of the diaphragmatic cupolæ.

Costo-diaphragmatic adhesions result in a flattening of the cupola during inspiration, and adhesions between the visceral and diaphragmatic pleura anchor the diaphragm to the lung and cause marked angulation during inspiration (*Fig.* 323).

Marked elevation of the right cupola was noticed in a case of subphrenic abscess (*Fig.* 311), where a large quantity of gas accumulated between the liver and the diaphragm, and again in a case of injury to the right phrenic nerve (*Fig.* 309). Marked elevation of the left cupola was noted in left lung collapse (*Fig.* 297), and could be detected both radiographically and by percussion by the abnormally high position of the stomach and colon gas-bubbles.

Injury to one side of the chest causes diminution in the inspiratory descent of the diaphragm on the affected side. No case has shown depression of the diaphragm beyond the normal inspiratory position, nor has any cupping of the upper surface of the diaphragm been observed.

It is rather difficult to explain the high immobile diaphragm which is the usual result of a wound of the chest. It is not a reflex contraction of the diaphragm to prevent movement, comparable to the rigid abdominal muscles found with peritonitis, since the diaphragm is in the fully relaxed position. Indeed, if it is a reflex, it must be a reflex relaxation of the muscle fibres. There is, however, a second possible explanation of the high immobile diaphragm—namely, that the diaphragm is unable to descend because the air cannot enter the lung owing to the compression of the latter by the fluid in the pleural cavity. In a case of apical traumatic infarct, each inspiratory effort was accompanied by an indrawing of the supraclavicular region and the upper intercostal spaces, and it is reasonable to assume that the diaphragm will have to labour against this abnormal negative pressure when air is unable to enter the lower lobe. Perhaps both factors come into play. Strong support is given to the reflex theory by those cases where the immobile diaphragm is unaccompanied by any other change in the lung area, or when only a small quantity of blood is present in the phrenico-costal space. One has observed several perforating wounds of the chest which at first showed only a high immobile diaphragm.

Localization of Metallic Foreign Bodies in the Thorax.—The localization may be carried out with the object of determining the anatomical position and reconstructing the track of the missile, or as a preliminary step in the removal of the foreign body. In the latter case the most important point for the surgeon is the determination of the portion of rib in closest proximity to the foreign body. This is most rapidly arrived at by screening antero-posteriorly and laterally, and then taking stereoscopic plates with the foreign body as near the plate as possible. Most intrathoracic foreign bodies would

appear to be brought to rest by the thoracic wall, and are therefore fairly accessible to the surgeon. Small fragments embedded in the region of the lung hilus will probably be left *in situ*.

The entire examination is made with the patient in the lying position, and a skin-mark is made over the most adjacent portion of rib. In taking the plates, the patient is instructed to hold his breath, and an exposure of ten to fifteen seconds, without an accelerator screen, is usually sufficient. A much longer exposure will be required in the presence of a hæmothorax.

Removal of Intrathoracic Metallic Foreign Bodies.—One of the most recent text-books on military surgery advocates no surgical interference with intrathoracic foreign bodies unless the foreign body is in the pleural cavity and is giving rise to symptoms. One's own experience, limited to ten operations for the removal of intrathoracic foreign bodies, does not disclose any difficulty in the operation, or any unfavourable complication in the convalescence. Consequently one is accustomed to undertake the removal of the foreign body when the patient complains of its presence, and when the missile is within reach of the surgeon's finger passed through a small thoracotomy opening.

Two inches of rib is resected, the pleural cavity opened, if necessary the lung incised, and the missile located by palpation. In the presence of adhesions no pneumothorax will take place; otherwise, the palpating finger will fairly efficiently block the pleura opening. Foreign bodies in the lung are easily palpated, and the intervening lung tissue is often friable, so that the finger can accomplish the loosening of the metal fragment, and forceps can extract it. After the removal has been accomplished, one closes the pleural opening and tightly sutures the overlying muscles and skin so as to prevent any communication with the outside air.

The wound of the lung appears to close rapidly, and the air is ultimately absorbed from the pleural cavity.

Changes in the Lung Areas produced by Wounds and Injuries.—The lung area is the clear space bounded medially by the mediastinum, laterally by the ribs, and inferiorly by the diaphragm. Radiating into it from the lung hilus are a number of opaque strands which are produced by the pulmonary vessels and the bronchi. The presence of fluid or gas in the pleural cavity, laceration or inflammation of the lung substance, and massive collapse of the lung, can be diagnosed by the alterations they produce in the lung area.

Where possible the patient should be examined both in the lying and sitting positions, with the rays passing dorso-ventrally, and the apparatus should be capable of giving a satisfactory result with a plate exposure of five seconds with an accelerator screen.

Fluid in the Pleural Cavity.—This gives rise to an opacity of the lung area, the extent of which varies with the amount of fluid. A very large quantity of fluid will render the whole of one lung area opaque, whilst a small collection will produce a supradiaphragmatic opacity in the sitting position. Where the whole lung area is not abolished in the sitting position, the upper limit of the fluid opacity is ill-defined and irregular, and forms a marked contrast to the clearly-defined horizontal gas-fluid junction. In large collections of fluid the clear space may be reduced to a pear-shaped area, the base of which corresponds to the lung apex, the stalk being directed towards the lung

hilus. In the lying position, fluid disseminates itself through the pleural cavity, and produces a moderate opacity of the whole lung area.

The nature of the pleural fluid cannot be determined radiographically.

Gas in the Pleural Cavity.—Gas in the pleural cavity, associated with retraction of the lung from the lateral thoracic wall, is revealed by the presence of an opaque line produced by the lateral margin of the collapsed lung, and even quite small collections of gas may disclose themselves in this way (*Fig.* 287). In the large pneumothorax, or in the presence of inflammatory thickening of the visceral pleura, the structure and outline of the whole lung and its lobes may be visible (*Fig.* 286).

Where, however, owing to fresh or old adhesions between the lung and the lateral thoracic wall, lateral collapse of the lung cannot take place, the gas tends to collect in front of the lung, and fails to alter the appearance of the lung area. In one case, a large pneumothorax was not recognized at the *x*-ray examination, but was subsequently revealed by exploratory puncture and confirmed by post-mortem examination. It was found that the lung was fixed by fresh adhesions to fractured ribs in the lateral thoracic wall, and that the gas had collected anterior to the lung.

In some cases the adhesions are unable to prevent lateral collapse of the apex (*Fig.* 313), or the lung may be permitted to retract upwards from the phrenico-costal space.

Gas and Fluid in the Pleural Cavity.—Gas and fluid in the pleural cavity give rise, in the sitting position, to a very characteristic picture, since a sharp horizontal line (gas-fluid junction) marks the junction of the opaque fluid with the transparent gas (*Fig.* 280). During screen examination this gas-fluid junction may show waves, bubbles, or splashings.

Traumatic Infarct.—This is the condition produced by contusion or laceration of the lung, and it gives rise to an opacity of the lung area involved. In *Fig.* 310 a traumatic infarct of the lung apex is illustrated. When the lower part of the lung is involved, some difficulty may be experienced in distinguishing a traumatic infarct from a small hæmothorax, and frequently the latter condition accompanies the former.

Pneumonia.—This gives rise to an opacity of the lung area concerned. There is no displacement of the heart.

Massive Collapse of the Lung.—Pasteur[1] has described this condition, and finds it in association with diphtheria and as a sequela of abdominal operations. The diphtheritic cases are the result of paralysis of the diaphragm, and the post-operative massive collapse is perhaps due to a reflex immobility of the diaphragm on the affected side. Sir John Rose Bradford has pointed out the frequency with which this condition accompanies gunshot wounds of the chest,[2,3] and was the first to suggest massive collapse as the explanation of certain puzzling radiograms, the outstanding feature of which is opacity of the lung area with retraction of the heart towards the opaque side.

Radiograms of fifteen of these cases have been obtained. In twelve the left and in three the right lung was affected. In ten cases the collapse was on the side opposite to that injured (contralateral collapse), and in five the collapse was on the same side as the injury (homolateral collapse). The missile may penetrate the thoracic cavity, or may merely give rise to a contour track.

As a rule the lower lobe alone is affected, but in one case the whole lung was opaque, and in one case the apex alone was affected. The evidence obtained from these cases is summarized in the following paragraphs.

1. Opacity of a lung area, associated with a high and immobile diaphragm and with retraction of the mediastinum towards the opacity, may follow a contour wound of the same side of the chest, or a contour wound or a penetrating wound of the opposite side of the chest.

2. The opacity gradually disappears, and the lung area is normal in from one to two weeks.

3. The gradual disappearance of the opacity is independent of the changes taking place in the opposite side of the chest (*Figs.* 287, 288, where the right pyopneumothorax continued to develop and the left lung opacity disappeared).

4. Complete paralysis of all the muscles of respiration, except the left half of the diaphragm, did not produce any opacity in the lung areas (*Fig.* 309).

5. The lower lobe of the left lung is most frequently affected.

6. When the left lung is affected, there is a marked increase in the area of cardiac pulsation, due to the retraction of the lung from the anterior surface of the pericardium.

7. As a rule a man lies on the unwounded side, and the restriction of the respiratory movements on the dependent side may be a factor in producing contralateral collapse.

8. The following physical signs accompany the opacity: Inspection—diminished respiratory movement in the affected region. Percussion—dullness posteriorly over the opaque area. Auscultation—weak breath sounds or tubular breathing over the opaque area, occasionally accompanied by râles or rhonchi.

9. One case of contralateral opacity with retraction of the heart developed pneumonia in the affected lung, and died. The post-mortem showed left lobar pneumonia and pericardial effusion. On the posterior aspect of the right chest there was a large gutter-wound, which was entirely superficial to the ribs.

10. Examination of this series of cases still leaves the cause of the opacity uncertain.

Bilateral Affections.—

Contralateral collapse	6 cases
Wound on opposite side to hæmothorax ..	5 ,,
Double hæmothorax	2 ,,
Left hæmothorax—right tubercle ..	1 ,,
Right hæmothorax—pericardial effusion ..	1 ,,
,, infarct—left collapse	1 ,,
,, pneumothorax—left collapse ..	1 ,,
,, effusion—left collapse	1 ,,
,, apical collapse—left apical traumatic infarct	1 ,,
,, empyema—left pneumonia ? ..	1 ,,
,, pneumothorax—left effusion ..	1 ,,
Total cases	21

Contralateral lung collapse accounts for a large number of bilateral affections, and in some of these the wounded side showed injury to the lung, or a collection of fluid, or gas and fluid, in the pleural cavity. The next largest group includes cases of double hæmothorax and of hæmo-

thorax with the entry wound on the opposite side. As a rule the missile enters the back, passes to the opposite side superficial to the spine, and then penetrates the thoracic cavity. In its passage it may injure both pleural cavities and produce double hæmothorax, or the track may be contour on one side and penetrating on the other. In two cases the missile entered the breast, and, after a contour track, penetrated the thoracic cavity of the opposite side.

Course of the Missile.—It is sometimes extremely difficult to reconstruct the thoracic track of a missile, owing to the possibility of free movement in the pleural cavity, and to the tendency of the ribs to produce deflection.

The following cases illustrate these points :—

1. A rifle bullet entered the right back 14 cm. to the right of the spine and on a level with the nipple. The bullet was removed from the left breast lateral to the nipple. An extensive left hæmothorax was produced, the opacity extending up to the fourth costal cartilage, and being accompanied by slight retraction of the heart to the left. No rib fracture could be detected, but one believes that the bullet passed superficial to the spine, and was then deflected by a rib through the left thoracic cavity.

2. A shrapnel ball penetrated the right back, superficial to the seventh rib and 7 cm. to the right of the spine. It was localized in front of the neck of the left twelfth rib, and a fracture of the left seventh rib lateral to the neck was present. The ball had passed transversely from right to left, superficial to the spine, fractured the seventh rib on the left side, and entered the pleural cavity, through which it descended to its resting-place.

Physical Signs.—Inspection, palpation, percussion, and auscultation were carried out at the time of the *x*-ray examination, so that the ordinary physical signs might be correlated with the radiogram, and a short description of the usual signs accompanying the various pathological conditions is given below. Deficient movement of one side of the chest is one of the most reliable signs, and always indicated the site of the pathological change. Surgical emphysema obscured the percussion results by giving rise to a tympanitic note, and radiography alone could be relied on to give an accurate diagnosis in such cases. As a rule surgical emphysema accompanied pneumothorax.

Auscultation would appear to be somewhat unreliable, since the same pathological condition may give rise to tubular breathing or weak breath sounds, or a patient may show a change from tubular breathing to weak or absent breath sounds. It has been suggested that this tubular breathing due to lung collapse, and that when the collapse passes off, the weak breath sounds of fluid in the pleural cavity appear. *Case* 9 (*Fig.* 296)—a typical lung collapse—does not support this theory, since it showed weak breath sounds and no tubular breathing.

Hæmothorax (59 cases).—

X-ray Appearances on Affected Side.—Diaphragm high and immobile. Heart displaced to sound side. An opacity of the lung area which in the sitting position occupies the whole lung area or leaves a variable amount of the upper region clear. Upper margin of the opacity irregular.

Percussion.—Posterior—dullness up to the inferior angle or spine of the scapula. Anterior—skodaic resonance (lower pitched and tympanitic).

Auscultation.—Posterior—breath sounds weak or absent ; in 5 cases

tubular breathing changing to weak or absent breath sounds; in 9 cases tubular breathing. ANTERIOR—weak breath sounds.

Traumatic Infarct (15 cases).—

X-ray Appearances.—Opacity in region of lung wound. In some cases fragments of bone or metal in the centre of the opacity. Posture has no effect on the opacity. Diaphragm immobile or acting.

Percussion.—Normal, or dullness over infarct.

Auscultation.—Weak breath sounds over infarct; tubular breathing in 1 case; adventitious sounds in 2 cases.

Surgical Emphysema.—Present in 3 cases.

Hæmopneumothorax (19 cases).—

X-ray Appearances (sitting position).—Diaphragm high and immobile. Heart displaced to sound side. Opacity of lung area, surmounted by a clear area, the junction being marked by a sharp horizontal line. Splashing sometimes seen at the gas-fluid junction.

Percussion.—POSTERIOR—dullness up to angle or spine of scapula, sometimes surmounted by a tympanitic note. ANTERIOR—skodaic resonance.

Auscultation.—POSTERIOR—weak or absent breath sounds; tubular breathing passing to weak breath sounds in 2 cases; tubular breathing in 3 cases. ANTERIOR—weak breath sounds. Coin sound in 3 cases.

Surgical Emphysema.—Present in 5 cases.

Pyopneumothorax (8 cases).—

X-ray Appearances (sitting position).—Lung area opacity, bounded above by a sharp horizontal line and surmounted by a clear area. Heart displaced to sound side. Diaphragm immobile on affected side.

Percussion.—POSTERIOR—dullness over lower part. ANTERIOR—very variable.

Auscultation.—POSTERIOR—tubular breathing or weak breath sounds. ANTERIOR—tubular breathing or weak breath sounds. (*Note.*—In 3 right-sided pyopneumothorax cases tubular breathing appeared over the left base.)

Pneumothorax (7 cases).—

X-ray Appearances.—Outline of collapsed lung visible. Unusually clear area lateral to lung and above diaphragm, with absence of lung mottling. Serous effusion soon appears. Adhesion of lung to injured portion of thoracic wall prevents complete collapse of lung. Heart displaced to opposite side.

Percussion.—POSTERIOR—tympanitic. ANTERIOR—tympanitic.

Auscultation.—Coin sound. Tubular breathing (amphoric in cases of open pneumothorax).

Surgical Emphysema.—Present.

Collapse (15 cases: left 12, right 3; contralateral 10, homolateral 5).—

X-ray Appearances.—Opacity of lower part or whole of one lung area, with retraction of heart to opaque side. Diaphragm on affected side high and usually immobile.

Percussion.—POSTERIOR—dullness.

Auscultation.—Tubular breathing or weak breath sounds. Occasionally râles or rhonchi.

Rapid recovery. Slight fever. History of having lain on the unwounded side for a period subsequent to injury. Increased area of cardiac pulsation with left-sided collapse.

PARTICULARS OF CASES.

Case 1.—**Copious right hæmothorax and its appearance after the removal of 1500 c.c. of fluid.**

Oct. 6, 1916.—Penetrating wound of the right side of the chest.

Oct. 10. Physical examination: *Right anterior*—diminished vocal fremitus; dullness; tubular breathing. *Right posterior*—diminished vocal fremitus; dullness; weak breath sounds.

Radiogram (*Fig.* 276). Heart displaced to the left; opacity of the whole right lung area.

On Oct. 17, 1500 c.c. of bloody fluid were aspirated from the right pleural cavity. Oct. 18. Physical examination: *Right anterior*—percussion note higher pitched and

FIG. 276.—*Case* 1, Oct. 10.

FIG. 277.—*Case* 1, Oct. 18.

more tympanitic than on the left side (sitting): absent breath sounds. *Right posterior*—vocal fremitus diminished below the scapula; dullness below mid-scapula; breath sounds absent.

Radiogram (*Fig.* 277). Sitting position. Heart has moved 2 cm. to the right since the previous examination; horizontal gas-fluid junction in right lung area; the lung apex can be seen above the level of the fluid.

Case 2.—**Perforation of the right chest with gradual development of a pyopneumothorax.**

Aug. 22, 1916.—Entry wound 3 cm. to the right of the spine and 17·5 cm. above the iliac crest. Exit wound in the right mid-axillary line 1 cm. below the level of the nipple. Weak breath sounds over the right base.

Radiogram (*Fig.* 278). A small quantity of fluid in the right pleural cavity.

Aug. 27. *Right posterior*—dullness; diminished vocal fremitus; pectoriloquy and faint tubular breathing below the level of the spine of the scapula; apex beat in the nipple line and in the fourth interspace.

Radiogram (*Fig.* 279). Plate in the sitting position shows opacity of the whole right lung area, with some displacement of the heart to the left. In the region of the first and second interchondral spaces the opacity shows increased density, and this darker area is limited above by a horizontal line or gas-fluid junction.

On Aug. 29, a needle passed through the posterior wall of the right chest at the level of the gas-fluid junction revealed the presence of gas and bloody

fluid; 30 c.c. were withdrawn. On Aug. 31, 700 c.c. of infected bloody fluid and some gas were aspirated from the right pleural cavity. Sept. 3. Rib resection and drainage of the right pleural cavity.

Fig. 278.—*Case* 2, Aug. 22.

Fig. 279.—*Case* 2, Aug. 27.

Case 3.—**Rapid recovery from a hæmopneumothorax, the result of a bayonet wound.**

Oct. 20, 1915.—The patient received numerous bayonet wounds of the trunk and extremities, and one of these wounds perforated the left anterior thoracic wall.

Oct. 23. Physical examination: *Left anterior* (lying position)—hyper-resonance; loss of breath sounds; metallic tinkling and coin sound. *Left posterior* (sitting position)—dullness over the lower part and loss of breath sounds.

Fig. 280.—*Case* 3, Oct. 23.

Fig. 281.—*Case* 3, Nov. 8.

Radiogram (*Fig.* 280). Screen examination in the sitting position showed dense opacity in the lower two-thirds of the left lung area, limited above by a gas-fluid junction. The surface of the fluid showed splashing. On Nov. 8, a second *x*-ray examination (*Fig.* 281) shows that the thorax is now normal.

This case is interesting on account of the rapid return to the normal. No exploratory puncture was made and no fluid was withdrawn.

Case 4.—**Hæmothorax becoming a hæmopneumothorax.**

Multiple wounds were received on the posterior aspect of the left shoulder.

Aug. 21, 1916.—Physical examination : *Left anterior*—skodaic resonance. *Left posterior*—dullness and tubular breathing over the lower part.

Radiogram (sitting) (*Fig.* 282). Heart displaced to the right, opacity of the left lung area extending as high as the third costal cartilage.

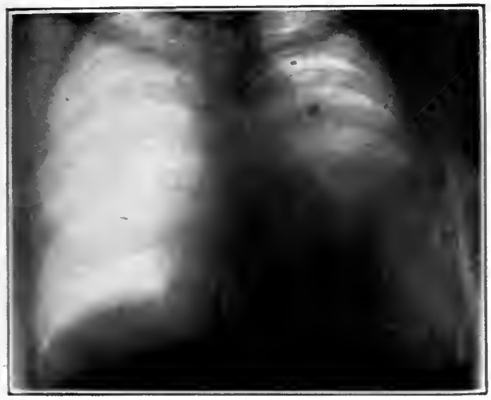

FIG. 282.—*Case* 4. Aug. 21.

FIG. 283.—*Case* 4. Sept. 4.

Sept. 4. Physical examination : *Left anterior*—percussion note lower pitched than on the right side. *Left posterior*—diminished vocal fremitus : dullness and weak breath sounds over the lower half of the lung.

Radiogram (sitting) (*Fig.* 283). A gas-fluid junction at the level of the fourth costal cartilage ; heart displaced to the right.

Case 5.—**Small right hæmothorax developing into a pyopneumothorax.**

The patient received a contour wound of the right side of the thorax some days previous to examination.

Sept. 17, 1916.—A piece of metal has fractured the right seventh and eighth ribs near the angles, during a contour course, and is lying lateral to the inferior angle of the right scapula.

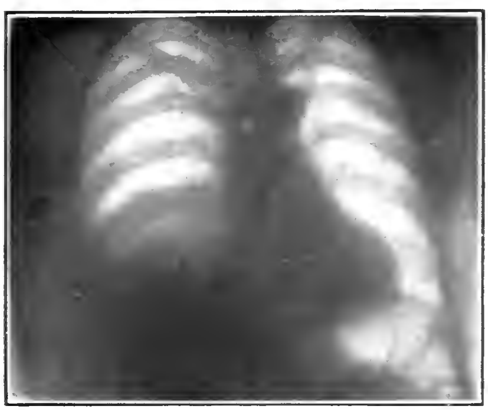

FIG. 284.—*Case* 5, Sept. 17.

Radiogram (*Fig.* 284). Taken in the sitting position ; opacity in lower part of right lung area ; heart displaced to the left.

Physical examination : Abdomen rigid ; dullness and tubular breathing at the base of the right lung.

Sept. 19. Physical examination : Pulse 116 ; respirations 36 ; temperature 103°. Apex beat one inch lateral to the nipple and in the fifth space. Both sides move equally in respiration. Abdomen slack. *Right anterior*—percussion note higher pitched than on the left side. *Right posterior*—diminished vocal fremitus ; moderate dullness below the level of the

mid-scapula ; weak breath sounds and diminished vocal resonance. *Left posterior*—tubular breathing and pectoriloquy below the level of the inferior angle of the scapula.

Oct. 13. *Radiogram* (sitting) (*Fig.* 285). Gas-fluid junction at the level of the second costal cartilage on the right side ; opacity infero-lateral to this junction. The edge of the partially collapsed upper lobe is visible above the junction. Physical examination : *Right anterior*—diminished expansion ; increased vocal fremitus ;

FIG. 285.—*Case* 5, Oct. 13.

FIG. 286.—*Case* 5, Oct. 20.

percussion note higher pitched than on the left. *Right posterior*—dullness ; diminished breath sounds and increased vocal resonance below the level of the inferior angle of the scapula.

Oct. 20. *Radiogram* (sitting) (*Fig.* 286) after drainage of the right pleural cavity. A drainage tube passes into the empyema cavity. The thickened visceral pleura enables one to distinguish the three lobes of the right lung.

Case 6.—**Perforation of the right side of the thorax leading to collapse of the left lung and a right pyopneumothorax.**

FIG. 287.—*Case* 6, July 16.

July 14, 1916.—Received wounds of the head, leg, and right side of the thorax, and was knocked against the side of the trench so that he became breathless for a few minutes. He then lay on his left side for forty-five minutes.

July 16. Physical examination : Respirations 40. Apex beat in the fourth space half an inch lateral to the nipple. Deficient movement on the left side. Marked cardiac pulsation in the second, third, and fourth left interspaces. Tubular breathing over the left lung anteriorly, and weak breath sounds posteriorly.

Radiogram (sitting) (*Fig.* 287). Heart displaced to the left ; opacity of the lower half of the left lung area. A piece of metal has perforated the right axillary thoracic wall and has given rise to a small pneumothorax in its immediate neighbourhood. The edge of the partially collapsed lung is visible.

July 22 *Radiogram* (sitting) (*Fig.* 288). The left lung opacity has cleared up : there is still displacement of the heart to the left. Gas and fluid are now present in considerable quantity in the right pleural cavity, and there is a double gas-fluid junction, one at the level of the second and one at the level of the third costal cartilage.

July 23. The right pleural cavity was drained, gas and pus escaping. The temperature, which had been high, came down to normal within one week, and remained so for a fortnight, when it began to show nocturnal elevations. A pure culture of *Bacillus perfringens* was obtained from the pus.

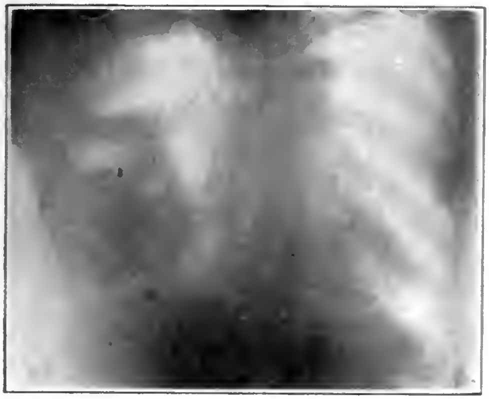

FIG. 288.—*Case* 6, July 22.

FIG. 289.—*Case* 6, Aug. 16.

Aug. 16. *Radiogram* (sitting) (*Fig.* 289). The right lung area shows a partially collapsed lung covered with thickened pleura ; lateral to the lung is the drained empyema cavity containing a drainage tube : crossing the lower part of the left lung area is a linear opacity, the nature and origin of which is doubtful. The heart is still somewhat displaced to the left.

The patient was evacuated to England in good condition.

Case 7.—**Right pneumothorax following fracture of ribs, and stages in its recovery.**

July 12, 1916.—Was blown up by a shell and severely bruised without receiving any superficial wound.

July 14. Physical examination : *Right posterior*—surgical emphysema and bell sound over lower half : tubular breathing and pectoriloquy medial to inferior angle of the scapula.

FIG. 290.—*Case* 7, July 14.

Radiogram (lying) (*Fig.* 290). Fracture of the sixth, seventh, and eighth ribs near their angles, on the right side. Collapse of the right lung and displacement of the heart to the left. Right cupola of the diaphragm immobile.

July 25. A *second radiogram* (sitting) (*Fig.* 291) shows a gas-fluid junction and a dense shadow in the cardio-hepatic angle. The heart has returned to the normal position. The pneumothorax has passed into a seropneumothorax.

July 26. Exploratory puncture of the right pleural cavity revealed gas and slightly blood-stained fluid.

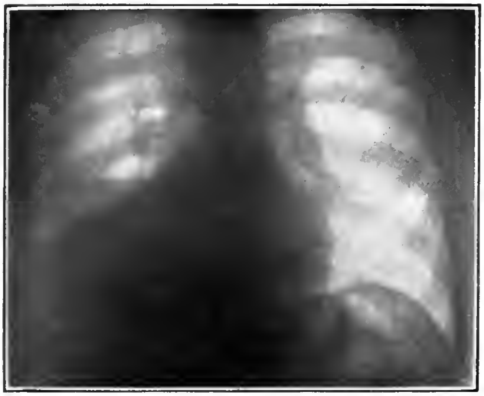

FIG. 291.—*Case* 7, July 25.

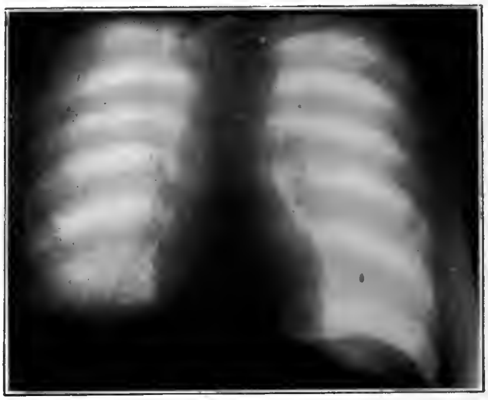

FIG. 292.—*Case* 7, Aug. 2.

A *third radiogram* (sitting) (*Fig.* 292), taken Aug. 2, shows a marked improvement in the appearance of the right side of the chest. There is still a small quantity of fluid in contact with the diaphragm.

Case 8.—**Pyopneumothorax.**

Sept. 16, 1916.—A missile traversed the right side of the chest and emerged some distance below the inferior angle of the scapula.

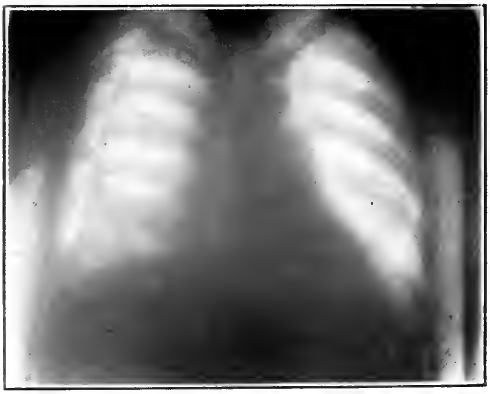

FIG. 293.—*Case* 8, Sept. 24.

Sept. 24. Physical examination: *Anterior*—the apex beat is in the fifth interspace 3 cm. lateral to the nipple. Skodaic resonance on the right side. Harsh loud breathing on the left side. *Posterior*—dullness, pectoriloquy, and well-marked bronchial breathing on both sides, extending up to the inferior angle of the left scapula and the spine of the right scapula. The bronchial breathing is much louder on the left side. Free discharge of pus from the exit wound, which opened into the pleural cavity.

Radiogram (sitting) (*Fig.* 293). Heart displaced to the left. Opacity of the lower part of the right lung area extending up to the level of the fourth costal cartilage. Superior to this the lung can be seen separated from the chest wall by gas.

Oct. 1. *Radiogram* (sitting) (*Fig.* 294). The heart has returned somewhat to the right. The opacity of the right lung area is now surmounted by a gas-fluid

junction at the level of the third costal cartilage. The lung is separated to a greater extent from the chest wall by gas, and there is an excellent demonstration of the partially collapsed lung.

Oct. 3. Rib resection below the inferior angle of the scapula. Pus was only reached on passing a tube upwards for several inches. There appears to have been

Fig. 294.—*Case* 8, Oct. 1.

Fig. 295.—*Case* 8, Oct. 16.

loculation of the pleural cavity, the lower loculus being well drained by the exit wound.

Oct. 16. *Radiogram* (sitting) (*Fig.* 295). Stereoscopic plates show adhesion of the right lung to the diaphragm and anterior thoracic wall. The tube is seen entering the pleural cavity, and the fluid level is lower than it was before the rib resection.

The patient was evacuated to England in good condition.

Case 9. — **Contralateral lung collapse following perforating wound of the right side of the thorax.**

Jan. 28, 1916.—A bullet entered the right side of the back, 12·5 cm. to the right of the mid-line and on a level with the first lumbar vertebra. A note from the casualty clearing station states: "Bullet extracted over eighth rib."

Jan. 31. Physical examination: The operation wound is situated over the right tenth costal cartilage. The bullet has probably perforated the diaphragm and liver. *Left anterior*—apex beat in the fourth left interspace 2·5 cm. lateral to the nipple. Skodaic resonance. *Left posterior*—absence of breath sounds in the lower part.

Fig. 296.—*Case* 9, Jan. 31.

Radiogram in the sitting position (*Fig.* 296) shows marked displacement of the heart to the left, and opacity of the whole left lung area. The left cupola of the diaphragm cannot be distinguished The right lung area is normal. Subsequent x-ray examinations showed rapid clearing of the left lung opacity.

a high position of the left cupola of the diaphragm, and a return of the heart to the normal position.

Feb. 1. *Second radiogram* (sitting) (*Fig.* 297). A collection of gas in the stomach and colon demonstrates the high position of the left cupola of the diaphragm. There is still marked opacity of the left lung and retraction of the heart to the left.

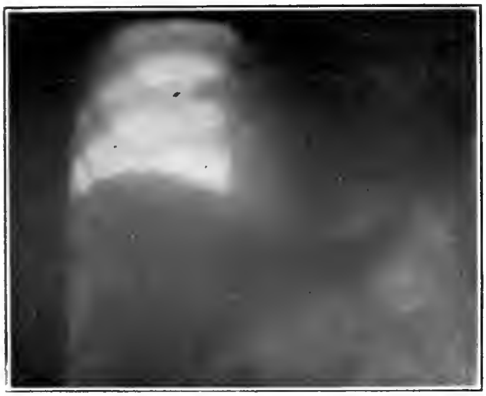

FIG. 297.—*Case* 9, Feb. 1.

FIG. 298.—*Case* 9, Feb. 14.

Feb. 14. *Final radiogram* (sitting) (*Fig.* 298). The heart is almost normal in position, the left lung opacity has disappeared. A ring of fuse wire marks the nipple.

Case 10. — **Contour wound of the left side of the thorax, producing a contralateral lung collapse.**

March 22, 1916.—Wounded by a shell fragment which entered the left mid-axillary line at the sixth rib, passed downwards and forwards superficial to the ribs, and entered the abdominal wall, where it came to rest at the junction of the left

FIG. 299.—*Case* 10, April 2.

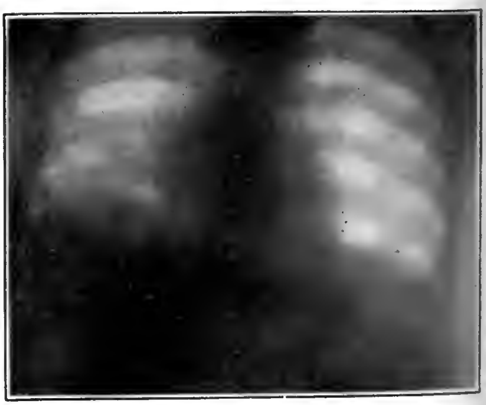

FIG. 300.—*Case* 10, April 15.

lateral and intertubercular planes. Immediately after being wounded the patient lay for some hours on his right side.

April 2. Physical examination : *Right posterior*—diminished vocal fremitus, dullness, and tubular breathing below the level of the spine of the scapula.

Radiogram (*Fig.* 299).—Screen and plate in lying position show marked retraction of the heart and mediastinum to the right, and opacity of the lower third of the right lung. The right cupola of the diaphragm was invisible.

Subsequently an abscess which developed in the abdominal wall was opened, and the metal fragment removed. Four further *x*-ray examinations were made, and revealed a gradual return of the heart to the normal position, and clearing of the right lung area. Owing to the condition of the abdominal wall, all these examinations had to be made in the lying position.

April 15. Fifth *x*-ray examination (*Fig.* 300) shows the heart still somewhat displaced to the right, but otherwise the thorax is normal.

Case 11.—**Superficial wound of the left side of the chest producing a homolateral lung collapse.**

April 11, 1916.—A piece of shell entered the left posterior axillary line, fractured the ninth rib, and rebounded into the extrathoracic tissues superficial to the fifth space in the mid-axillary line. A drainage tube was passed down to the fractured rib.

April 14. Physical examination: Apex beat in the nipple line. *Left anterior*—skodaic resonance and weak breath sounds. *Left posterior*—dullness below the level of the spine of the scapula; bronchophony in the region of the inferior angle of the scapula.

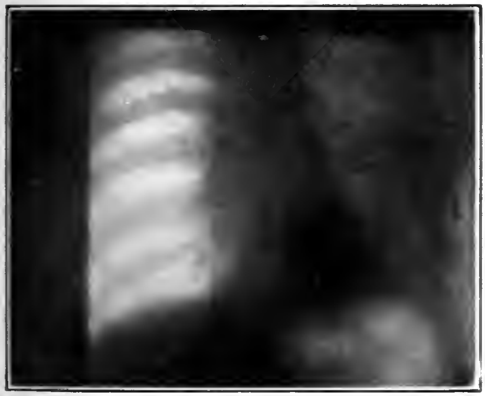

Fig. 301.—*Case* 11. April 14.

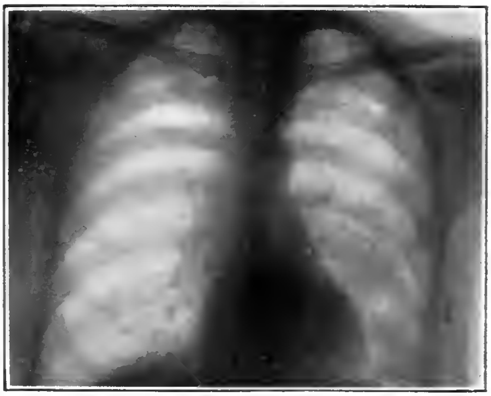

Fig. 302.—*Case* 11. April 30.

Radiogram (sitting) (*Fig.* 301). Piece of metal lying in the left lateral thoracic wall superficial to the fifth interspace. Fracture of the upper margin of the left ninth rib in the posterior axillary line. A drainage tube passes into the eighth interspace at the seat of fracture. Opacity of the left lung area. Marked retraction of the heart to the left. Abnormally high position of the left cupola of the diaphragm.

April 19. Coarse rhonchi over the front of the left side of the chest, and tubular breathing over the posterior aspect inferior to the spine of the left scapula.

April 30. *Radiogram* (sitting) (*Fig.* 302). Marked clearing of the left lung area, associated with return of the heart to the normal position.

Case 12.—**Left traumatic infarct associated with a right apical collapse following perforation of the upper part of the left side of the chest.**

A missile entered the left back medial to the vertebral border and at the level of the spine of the scapula. It fractured the second, third, and fourth ribs, and emerged above the centre of the left clavicle. Hæmoptysis on two succeeding days.

Oct. 4, 1916.—A few days after being wounded the condition was as follows: *Anterior*—marked indrawing of the left infraclavicular region during inspiration; a

higher pitched and less resonant note below the right clavicle; rhonchi on both sides. *Right posterior*—bronchial breathing above the spine of the scapula.

Radiogram (sitting) (*Fig.* 303). Both cupolæ of the diaphragm move well. Retraction of the superior mediastinum to the right. Fracture of the axillary portions of the left second, third, and fourth ribs, with separation of the fractured ends. Opacity of the left lung apex, extending inferiorly to the level of the first

FIG. 303.—*Case* 12, Oct. 4.

FIG. 304.—*Case* 12, Oct. 18.

interchondral space. Opacity of the right lung apex extending inferiorly to the level of the second interchondral space.

Oct. 12. Physical examination: *Right anterior*—normal. *Left anterior*—diminished expansion, apex beat in the fourth space $2\frac{1}{2}$ inches from the mid-line, higher pitched note. *Left posterior*—dullness and diminished vocal resonance above the spine of the scapula, weak breath sounds above the mid-scapula.

Radiogram. Clearing of both lung apices. Superior mediastinum returning to the normal position.

Oct. 18. *Radiogram* (sitting) (*Fig.* 304). Thorax normal apart from the fractured ribs. Physical examination: *Left anterior*—diminished expansion; diminished vocal fremitus; low pitched and more tympanitic percussion note; very weak breath sounds.

FIG. 305.—*Case* 13, July 7.

Case 13.—**Left basal pneumonia.**

July 3, 1916.—Patient felt out of sorts. July 4, acute pain in the left side; breathing difficult.

July 7. Physical examination: Temperature 104°; respirations 40; pulse 120. Tubular breathing and coarse crepitations at the left base.

Radiogram (sitting) (*Fig.* 305). Opacity of the lower half of the left lung area; no displacement of the heart.

July 18. *Second radiogram* (sitting) (*Fig.* 306). Left cupola of the diaphragm somewhat higher than normal: complete clearing of the left lung area.

Note.—This case should be contrasted with lung collapse, where there is always marked displacement of the heart.

Fig. 306.—*Case* 13, July 18.

Case 14.—**Perforation of the right side of the chest and subphrenic region resulting in a right empyema and pericarditis. Death.**

Sept. 14, 1916.—Wounded. The missile entered the fifth interspace 2 cm. to the right of the mid-sternum, and emerged 14 cm. to the right of the spine and 10 cm. above the iliac crest. The subsequent post-mortem examination showed that it opened the right pleural and pericardial cavities, traversed the diaphragm, liver, and peritoneal cavity, and emerged through the posterior abdominal wall.

Sept. 18. Physical examination: *Left anterior*—visible pulsation in the second, third, and fourth left interspaces: apex beat in the fifth interspace 7 cm. lateral to the nipple; percussion note higher pitched than on the right side: the stomach note passes up to the fifth interspace in the left mid-axillary line. *Left posterior*—tubular breathing and pectoriloquy extending as high as the inferior angle of the scapula.

Radiogram (sitting) (*Fig.* 307). Right cupola of the diaphragm almost immobile; left cupola of the diaphragm invisible: displacement of the heart to the left.

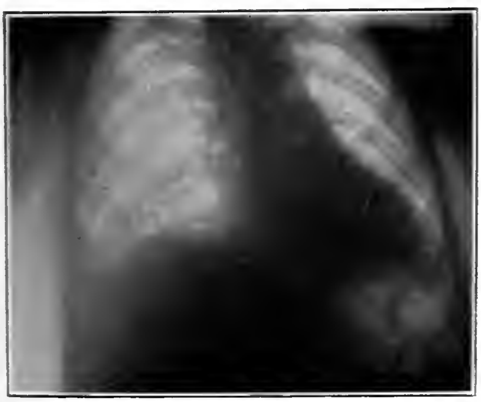

Fig. 307.—*Case* 14, Sept. 18.

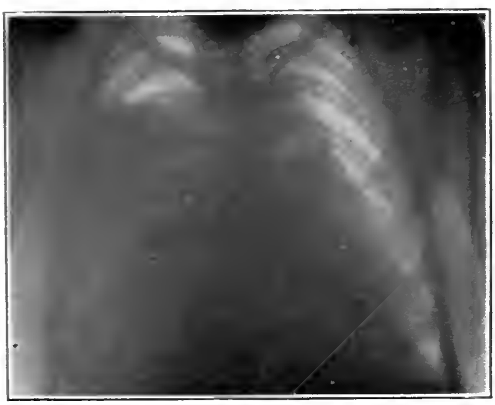

Fig. 308.—*Case* 14, Sept. 28.

For nine days the patient improved, the pulse dropping from 104 to 64, the respirations from 32 to 20, and the temperature to 99°.

Sept. 25. Weak breath sounds and râles at both bases: no change in apex beat. Next day sudden acute shooting pain along the track of the missile, and marked elevation in the temperature, pulse rate, and respiration rate.

Sept. 27. 1050 c.c. of sterile serous effusion removed from the right pleural cavity, resulting in relief of the dyspnœa; tubular breathing at both bases; diminished vocal fremitus over the right base.

Sept. 28. *Radiogram* (sitting) (*Fig.* 308). Opacity of the lower two-thirds of the right lung area; marked displacement of the heart to the left.

Sept. 29. From the right pleural cavity 750 c.c. of slightly turbid fluid were removed.

Subsequently the patient seemed to improve. The temperature fell to normal and he felt much better, but on Oct. 9 he died quite suddenly.

Post-mortem.—Pericarditis with effusion; right empyema, with the lung adherent anteriorly, and a small loculation postero-inferiorly; subphrenic adhesions; left lung normal.

Note.—Rib resection and drainage of the right pleural cavity should have been performed.

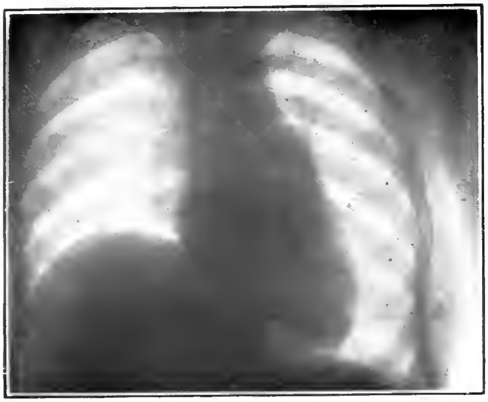

FIG. 309.—*Case* 15.

Case 15.—**Paralysis of all the muscles of respiration except the left half of the diaphragm.**

A shrapnel ball perforated the right sternomastoid muscle at the level of the fifth cervical vertebra, passed obliquely downwards and to the left posterior to the carotid sheath, traversed the neural canal of the seventh cervical vertebra, entered the left thoracic cavity, and came to rest on the visceral aspect of the left third rib, lateral to its neck.

Screen examination showed the right cupola of the diaphragm immobile and in position of full expiration.

Radiogram. A plate taken in the sitting position and at the end of a full inspiration is reproduced (*Fig.* 309). The left nipple is marked by a fuse wire. Note the abnormal difference in level of the two cupolæ of the diaphragm and the peculiar appearance of the heart.

This case is of especial importance in considering the etiology of lung collapse, since we have here a lung retaining its normal *x*-ray appearance when all its muscles of respiration are paralyzed.

There was loss of sensation below the third costal cartilage and paralysis of the right arm, lower extremities, abdominal muscles, and the intercostals.

The patient was evacuated to England, and the further course of the case is unknown.

Case 16.—**Right apical traumatic opacity surrounding a lung perforation.**

A shrapnel ball entered below the junction of the outer and middle thirds of the right clavicle, and was removed from the muscles of the back, one inch to the left of the midline and two inches above the inferior angle of the scapula. The percussion note over the right apex was higher pitched and less resonant, and the breathing was tubular.

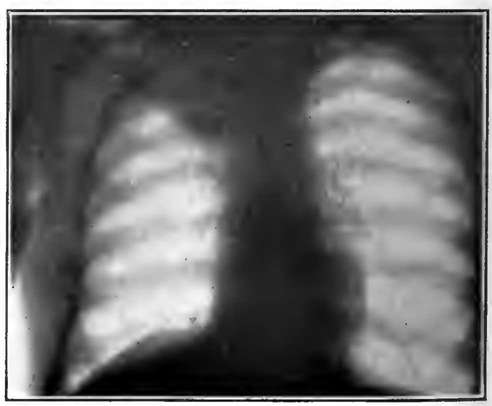

FIG. 310.—*Case* 16.

Radiogram (*Fig.* 310) is reproduced from a plate taken in the sitting position and at the end of a full inspiration. The fuse wire is on the operation wound. Note the opacity at the right apex and the absence of fluid in the pleural cavity. Two weeks intervened between the injury and the *x*-ray examination.

Case 17.—**Accumulation of gas between the right cupola of the diaphragm and the liver.**

Oct. 16, 1915.—Wounded in the cæcal region. An operation was performed in a casualty clearing station, and no perforation of the bowel found. Was admitted to this hospital with a diagnosis of peritonitis and right basal pneumonia.

Signs and Symptoms.—Temperature was of a septic type, being elevated at night and normal in the morning; blood-stained sputum: dullness, tubular breathing, and fine râles at the right base; swelling and tenderness in the epigastrium.

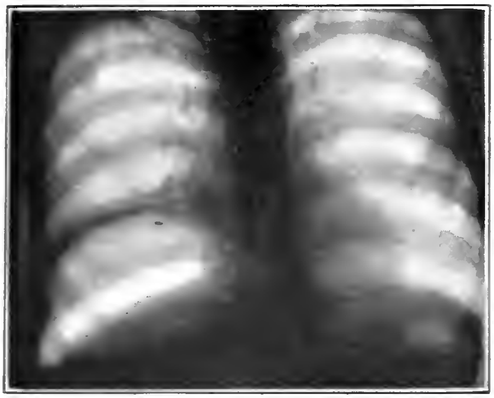

Fig. 311. *Case* 17. Nov. 6.

Percussion.—Along the right nipple vertical line one passed from normal lung note to a tympanitic note at the fourth costal cartilage. This was maintained to the costal margin, where it passed into a narrow band of liver dullness.

Nov. 6, 1915. *Radiogram* (*Fig.* 311). The right cupola of the diaphragm forms a thin opaque septum, convex upwards, between the much diminished right lung area and the large suprahepatic gas-bubble. This gas-bubble extends from the eighth to the tenth rib. Slight respiratory movement was observed in this part of the diaphragm.

Nov. 7. A portion of the tenth rib was removed in the right anterior axillary line by Major Maynard Smith. A large quantity of gas and a little pus were evacuated.

Nov. 9. Discharge of fæces from the operation wound.

Nov. 16. A second radiogram showed a very marked diminution in the size of the right subphrenic gas-bubble. The patient was shortly afterwards evacuated to England in good condition.

Case 18.—**Aneurysm of the ascending arch of the aorta, due to disease.**

Fig. 312.—*Case* 18.

The patient was admitted to the base hospital with the diagnosis of aortic aneurysm.

Physical examination: Apex beat in the fifth space half an inch lateral to the nipple: pulsating area below the right clavicle: weakness of the left radial pulse; right infraclavicular and parasternal area of dullness: systolic and diastolic murmurs at the apex and base.

Radiogram (*Fig.* 312). A large abnormal sharply-defined opaque area projects into the right lung area from the mediastinum. No expansile pulsation could be seen, but the medial portion of the lower border showed slight movement.

Case 19.—**Adhesion of lung to fractured ribs, preventing complete collapse of the lung in a pneumothorax.**

Large gutter wound of the back below the inferior angle of the right scapula.

Sept. 19, 1916.—Physical examination : *Right anterior*—low-pitched and resonant percussion note : complete absence of breath sounds. *Right posterior*—high-pitched dull percussion note ; no breath sounds.

Radiogram (sitting) (*Fig.* 313). The right cupola of the diaphragm is depressed, and shows slight respiratory movement : it is surmounted by an abnormally clear area. The heart is displaced to the left. The outline of the partially collapsed right lung is visible, and the following points are demonstrated : (*a*) The lung apex has collapsed by the approximation of the axillary, costal, and mediastinal surfaces ; (*b*) The lung is adherent to the ninth rib in the mid-axillary line ; above this point it has receded medially from the chest wall ; (*c*) The lower part of the lung has shrunk upwards so as to leave a clear gas-containing space between the lung and the diaphragm. Fracture of the right ninth and tenth ribs, lateral to the angles.

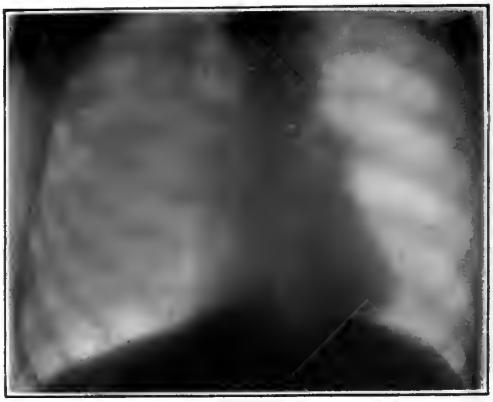

Fig. 313.—*Case* 19.

Case 20.—**Drained empyema showing partial subdivision into two cavities by an adhesion of the lung to the lateral chest wall.**

Admitted to hospital with a septic wound of the left hand and a temperature showing an evening rise to 103°. Cough, sweating, and signs at both lung bases developed. A needle passed into the right posterior axillary line drew off some blood.

Fig. 314.—*Case* 20, June 9.

April 30, 1916.—*X*-ray examination four weeks after admission into the hospital showed : opacity of the right lung area ; right cupola of the diaphragm invisible ; displacement of the heart to the left.

May 1. Exploratory puncture below the inferior angle of the right scapula revealed pus ; a rib was resected and the right pleural cavity drained.

June 9. *Radiogram* (*Fig.* 314). The right lung is partially collapsed, and leaves a clear space laterally, which is partially separated into upper and lower compartments by an adhesion between the lung and the lateral thoracic wall. The drainage tube passes upwards posterior to this adhesion.

July 26. *X*-ray examination shows no change in the thoracic picture.

Case 21.—**Left empyema in process of recovery.**

Dec. 19, 1915.—Wounded. On admission there were several wounds on the back and buttocks, and air was passing in and out through an opening to the left of the spine and over the ninth rib. Drainage of the left pleural cavity was maintained through this opening for the ensuing two months.

Feb. 17, 1916. *Radiogram (Fig. 315).* A large piece of metal in the left pleural cavity, between the diaphragm and the posterior part of the tenth rib. The heart lies almost entirely to the right of the middle line. A few small dense opacities in the right lung area. The lateral margin of the left lung can be faintly seen as it passes vertically upwards from the diaphragm, lateral to the metal fragment, to fuse with the anterior portion of the third rib.

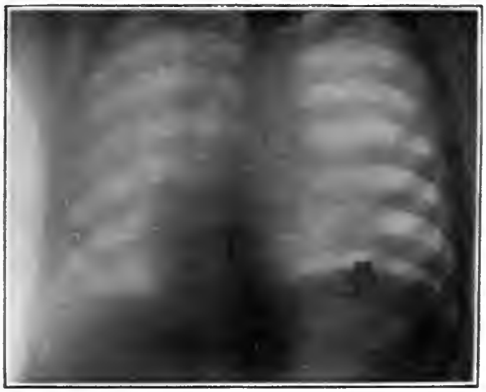

Fig. 315.—*Case* 21, Feb. 17.

Fig. 316.—*Case* 21, Feb. 24.

Feb. 24. *Second Radiogram (Fig. 316).* Since the previous week the heart has returned somewhat to the left side, but is still far from its normal position. The left cupola of the diaphragm is higher than normal, and there is a collection of gas in the stomach and colon. The lateral margin of the left lung is still visible, and has not altered its position. The high position of the left cupola of the diaphragm indicates the return of negative pressure in the left pleural cavity.

Case 22.—**Perforation of the left side of the chest resulting in pyopneumothorax with adhesions. Retraction upwards of the lower lobe of the lung is well demonstrated.**

Fig. 317.—*Case* 22, Oct. 2.

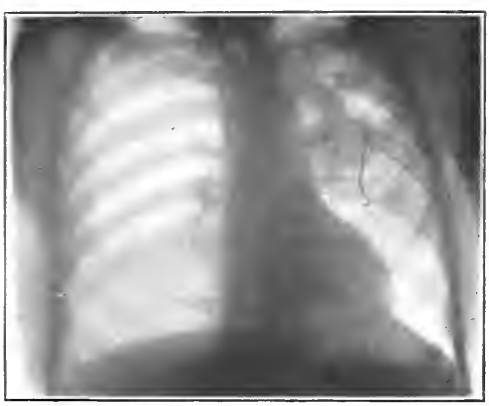

Fig. 318.—*Case* 22, Oct. 16.

Sept. 25, 1916.—A shrapnel ball entered superficial to the sternal end of the left clavicle and half an inch lateral to the sternoclavicular joint. A few days later

the ball was removed from the back, where it lay superficial to the inferior angle of the left scapula.

Oct. 2. Physical examination: Respirations 32; pulse 92; temperature 103°. *Left anterior*—dullness and very weak breath sounds over the first and second interspaces. *Left posterior*—normal.

Radiogram (sitting) (*Fig.* 317). A piece of wire lies embedded in the left lung lateral to the hilus. There is a gas-fluid junction at the level of the second interchondral space. Inferior to this level the left lung area is moderately opaque, with the exception of a supradiaphragmatic triangular clear area. It is probable that the lower lobe has retracted upwards from the diaphragm, leaving its bed to become occupied by gas.

Oct. 10. Purulent fluid is being discharged through the entry wound. Oct. 16. Temperature normal. Exploratory puncture 6 cm. inferior to the lower angle of the scapula is negative.

Radiogram (sitting) (*Fig.* 318). Impaired movement of the left cupola of the diaphragm. The heart shows some retraction to the left. Marked clearing of the left lung area, with disappearance of gas-fluid junction and a change in the position of the wire, indicating descent of the lower lobe of the lung.

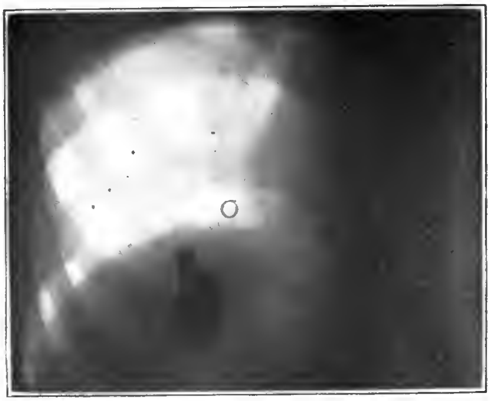

FIG. 319.—*Case* 23.

Case 23.—**A large fragment of metal in the right pleural cavity.**

Radiogram (*Fig.* 319). Shows the fragment lying in the right pleural cavity, posterior to the sixth costochondral joint. Removed at a subsequent operation.

Case 24.—**Right hæmothorax, and shrapnel ball in the pericardial cavity.**

A shrapnel ball entered the back 10 cm. to the right of the spine and over the tenth rib, perforated the lower lobe of the right lung, and probably entered the

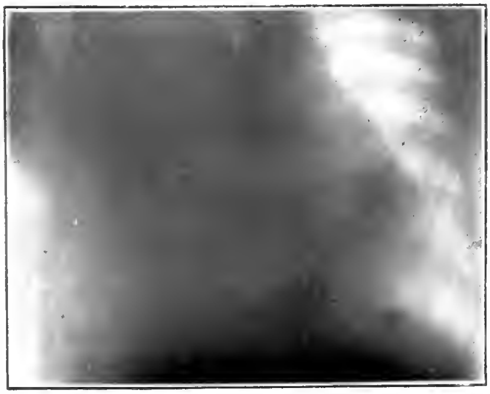

FIG. 320.—*Case* 24, Aug. 22.

FIG. 321.—*Case* 24, April 20.

pericardial cavity between the œsophagus and the inferior vena cava. It gave rise to a right hæmothorax and pericarditis.

Aug. 22, 1916.—Physical signs *Right posterior*—weak breath sounds and dullness. *Anterior*—apex beat in the sixth space three inches lateral to the nipple; pericardial rub.

Radiogram (sitting) (*Fig.* 320). Opacity of the whole right lung area, with displacement of the heart to the left. Shrapnel ball close to posterior surface of heart. Exploratory puncture of the right pleural cavity revealed sterile bloody fluid.

Sept. 9. Physical signs: *Right posterior*—dullness and weak breath sounds below the spine of the scapula. *Right anterior*—weak breath sounds.

Radiogram (sitting) (*Fig.* 321). The left margin of the heart has moved two inches to the right, and the shrapnel ball has moved with it. Some clearing of the right lung opacity supero-medially.

Case 25.—**Large piece of metal embedded in the left lung. Removed at a subsequent operation.**

Dec., 1916.—The patient was wounded by a piece of shell which entered the back in the middle line and 11 cm. below the inferior angle of the scapula. There was a history of aspiration of blood from the left pleural cavity.

April 20, 1917.—*Radiogram* (sitting) (*Fig.* 322). Showed immobility of the left cupola of the diaphragm, with marked angulation due to adhesion between the

FIG. 322.—*Case* 25, Sept. 9.

diaphragmatic and visceral pleuræ. The lateral portion of the left lung area was somewhat opaque, and a large fragment of shell was embedded in the lung 12 cm. anterior to the posterior skin mark.

A portion of rib was resected antero-inferior to the inferior angle of the left scapula. Sutures were passed with the object of anchoring the lung to the exposed parietal pleura, and some bubbling took place at the upper angle. Subsequently these sutures were found to have been unnecessary, as the parietal and visceral pleuræ were fused into a thick membrane. The pleura and lung were incised, the finger was inserted, and the metal fragment located by palpation. One was impressed with the extreme hardness of the heart, and the friable condition of the lung, which easily enabled the palpating finger to lay bare the foreign body. A pair of forceps, slipped along the finger, completed the extraction. The pleura, muscles, and skin were sutured, and collodion was applied. Apart from slight hæmoptysis and an evening rise of temperature to 100° for five days, there were no subsequent complications. The wound healed by first intention, and the patient was perfectly well at the end of a fortnight.

A skiagram taken two weeks after operation showed no change in the thoracic picture apart from the absence of the foreign body.

Case 26.—**Perforating wound of the right side of the chest.**

This skiagram (*Fig.* 323) was taken two months after the infliction of the wound. The exposure was made during full inspiration, and marked angulation

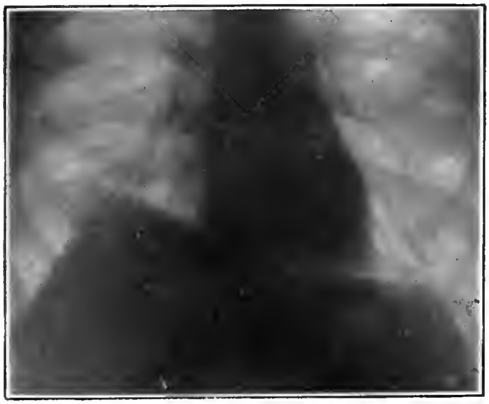

FIG. 323.—*Case* 26.

of the right cupola of the diaphragm is revealed. This is due to adhesions between the visceral and diaphragmatic pleuræ.

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[2] ROSE BRADFORD, *Brit. Jour. Surg.*, iii, 247.
[3] ROSE BRADFORD, *Brit. Med. Jour.*, 1917, Aug. 4

TWO CASES OF KERATODERMIA BLENNORRHAGICA.

By Captain CRAWFORD LUNDIE, R.A.M.C.

History and Literature.—All the literature consulted credits Vidal with being the first to describe a case of this rare disease in 1893. Sequeira and Turnbull described the first case recorded in England in 1910. Simpson published a very complete article on the subject in the *Journal of the American Association*, Aug. 12, 1912, giving a synopsis of all previously reported cases. Luys refers to monograms by Vidal, Jeanselme, Jacquet, Chauffard, and Le Damany, and quotes the description given by the last named. Watson, of Glasgow, in his treatise published in 1914, refers to a total of some twenty-five cases reported in all literature up to that time. Graham Little described the condition in the *Practitioner*, 1916, and gave a synopsis of thirty-eight previously reported cases. Three cases occurred in a general hospital, and were reported by Captain Brown, R.A.M.C. Two cases have been reported by French authors in *Les Annales des Maladies Vénériennes* of this year—the first by Gougerot and Clara in February, and the second by Montpellier in May. Two cases have occurred in another general hospital.

Description.—The condition is most characteristic on the most common site, viz., the soles of the feet. Here it begins as a small conical protuberance of a pinkish colour, hard to the touch like a corn, and quite painless: further, it may appear while the patient is in bed and not exposed to the conditions producing corns. As it progresses the central cone becomes brownish, but a pink circle persists round the base like the cambium layer in a growing plant. The cone now assumes the appearance of a blister, but when opened is found to contain no fluid, only a pasty mass of epithelial cells. In the later stages, or under treatment, the pink 'growing' circle becomes white, the cone-shaped mass withers, as it were, and drops off, leaving a pink base and no infiltration of the normal skin, so that no permanent scar is left as in syphilides, which are the lesions most likely to be confused with it.

This is the description of the individual lesions as seen in the present two cases, and agrees fairly closely with the descriptions by French writers of what they describe as "nail-like horns" and "dry blisters," according to the stage of the growth of the lesion. Sequeira also gives an apt description when he likens them to "sloes embedded in the skin." When grouped, the lesions exactly correspond to Sequeira's description, "like mountain ranges on a relief map." (*Fig.* 324.)

Pathology.—The gonococcus seems never to have been found in these lesions, but they are invariably accompaniments of gonorrhœa, generally of old standing, and always with blood infection, evidenced in most cases by

arthritis, and often by cachexia. Jacquet, Chauffard, and Fiessinger have worked on the pathology. They failed to inoculate animals or normal men with it, but they succeeded in inoculating a sound piece of skin on the patient himself with skin débris scraped from the lesions. Gougerot and Clara agree with these authors in believing the condition to be a gonococcal, dry, hyperkeratosic pyodermia, whose origin is favoured by a combination of: (1) Suitable terrain; (2) Epidermic maceration (inoculation under a watch-glass); (3) Inoculation with products of keratosic scratching. In the present cases the lesions began in each case on epidermis macerated by a Scott's dressing.

FIG. 324.—A case of keratodermia blennorrhagica.

Treatment.—All the monograms consulted agree that the essential part of the treatment is to cure the general gonorrhœal infection. All but one, that of Gougerot and Clara, recommend no local treatment. Nearly all recommend vaccine treatment. Gougerot and Clara found resorcin dressings useful. Watson recommends urotropine internally. Graham Little says vaccines are the only treatment, and seems to have found them always effectual. So far as the skin condition is concerned, this was not so in Montpellier's case, nor in the first case here, which developed keratosis *while actually having vaccine treatment.*

Case I.—C——, age 30, was admitted to a general hospital, on **Feb. 26, 1917,** suffering from acute gonorrhœa of eleven days' duration. He had had gonorrhœa ten years ago. On admission he had conjunctivitis, and a smear was taken to examine for gonococcus. This was negative, but arthritis of the left ankle developed

next day, proving there was blood infection. The eye condition was probably also an indication of blood infection. He was put on treatment that had proved very satisfactory in many joint cases, viz., sensitized gonococcal vaccine of the strength 100 million per c.c., administered as follows: First day, $\frac{1}{4}$ c.c.: second day, $\frac{1}{2}$ c.c.; third day, $\frac{3}{4}$ c.c.; fifth day, 1 c.c.; seventh day, $1\frac{1}{2}$ c.c.: ninth day, 2 c.c.; twelfth day, $2\frac{1}{2}$ c.c.; fifteenth day, 3 c.c.; eighteenth day, $3\frac{1}{2}$ c.c.; twenty-second day, 4 c.c.; twenty-sixth day, $4\frac{1}{2}$ c.c.; etc. Locally, the joint was treated with Scott's dressings.

The joint improved very much on this treatment, and the temperature got less, but the patient complained always of vague muscular pains, which seemed to be an indication of generalized infection. He was also thin from the first, though wasting increased later. On March 15 there appeared what looked like condylomata on the penis, and transfer to the syphilis side was contemplated; but before this was arranged the 'condylomata' had disappeared, and the typical lesions of keratodermia blenorrhagica had appeared on the feet (March 16). They were in the very early stage, and were all pink. As it was judged imprudent to diagnose this rare condition after seeing only one case previously—Captain Brown's first—the other two officers on the staff who had seen that case were asked to examine the patient. After careful consideration, they agreed with the diagnosis. In view of Graham Little's high claims for vaccine treatment, it was rather disconcerting to find a case develop this condition while actually having vaccines.

On the advice of Captain Haworth, who made the vaccine, it was suspended, and when the ankle swelled again it was aspirated to relieve pressure and pain. The fluid, however, seemed to come rather from the tissues than from the joint. Next day the ankle was œdematous, and pitted on pressure, but the urine was free from albumin. Scott's dressing was stopped on March 26, as the skin was getting tender. On March 28 the left knee contained fluid, and $3\frac{1}{2}$ c.c. of vaccine were given to combat this. On March 31 the knee was aspirated and culture attempted in the hope of making an autogenous vaccine. There was no growth. A dose of 4 c.c. of vaccine was given on April 2, and then the course was suspended, as the patient seemed very sensitive to it, as shown by rise of temperature. On April 12, a growth of gonococcus was got from fluid aspirated from the right knee, but the strain could not be established, and again autogenous vaccine was impossible. Another attempt at culture failed, and no further fluid was available, as the joints ceased to accumulate fluid.

Meanwhile the keratosis spread up the legs, and later appeared on hands, arms, and penis. The prostate was almost normal, but in the discharge obtained from it was the diphtheroid bacillus so often found in chronic gleets. By Captain Haworth's advice, therefore, the patient was put on the triple vaccine containing gonococci 50 million, diphtheroid bacilli 100 million, and staphylococci 100 million per c.c. This was given very gradually, at intervals of five or six days, thus: First dose, $\frac{1}{4}$ c.c.; second dose, $\frac{1}{4}$ c.c.; third, $\frac{1}{2}$ c.c.; fourth, $\frac{1}{2}$ c.c.; fifth, $\frac{3}{4}$ c.c.; sixth, $\frac{3}{4}$ c.c.; and so on. At the same time, he was, by Sir J. Rose Bradford's advice, put in the open air every fine day. A gradual improvement in temperature and general condition set in. The nourishing diet and the tonic of quinine, strychnine, and iron which he had had from the first were continued. Later, Captain Haworth advised another course of sensitized vaccine, as follows: First day, 1 c.c.: fifth day, 2 c.c.; ninth, 4 c.c.; thirteenth, 6 c.c.; and so on, every fourth day, up to 12 c.c. He improved more rapidly on that, and by July 1 his temperature was normal. He was well enough soon after to be evacuated to England; but keratosis was still present, though the joints and general condition were much better. In this he resembled Montpellier's case.

Case 2.—R——, resembled the case of Gougerot and Clara, in that he was not desperately ill, and walked into hospital. He had fluid in his right knee, which he said was traumatic, due to a twist two years ago. It was too like gonorrhœal not to be treated as such, and the left ankle developed arthritis while he was in bed with the right knee. Keratosis developed at the site of a Scott's dressing on the left ankle,

but soon reacted, as did also the joints, to sensitized vaccines, administered according to the last-mentioned method. He said he had had the skin condition before his present attack of gonorrhœa, and denied a previous attack. In this he is again like Gougerot and Clara's case, for their patient also denied ever having had gonorrhœa, although arthritis and stricture proved that he had, as did a hard and nodular prostate in the present case. The temperature was normal throughout.

Gougerot and Clara believe the skin lesion to be absolutely characteristic, and they claim to have diagnosed an old gonorrhœa from a cast in a museum by means of it.

The recurrence of keratosis with a fresh attack of gonorrhœa in the second case agrees with Le Damany's observation that such relapses of keratosis frequently follow fresh gonorrhœal infection.

The first case was also seen by Major McCormac, who confirmed the diagnosis, and by Sir George Makins, whose interest in the case secured the services of an artist to make the coloured drawing which accompanies this paper.

This opportunity is taken of thanking all the officers mentioned for their assistance and interest, and particularly Sir George Makins, at whose special request this paper has been written for publication.

SEPTICÆMIA AS A COMPLICATION OF GUNSHOT WOUNDS, WITH NOTES ON 13 CASES.

By Captain H. M. ANDERSON, R.A.M.C.,
and Captain G. RICHARDSON, R.A.M.C.

In the study of a series of cases of septicæmia occurring as a complication of gunshot wounds, three facts of very great interest present themselves: (1) The diversity of organisms which may produce septicæmia; (2) The diversity of clinical pictures produced by similar organisms circulating in the blood in the living state; (3) The presence of living organisms in the blood accompanied by no serious manifest symptoms.

1. *The diversity of organisms which may produce septicæmia.*—In the series of thirteen cases of which clinical records are appended, the following organisms were found to be present in the blood in the living state: (*a*) Streptococci; (*b*) *B. Welchii* (bacilli of gas gangrene); (*c*) *B. œdematis maligni*; (*d*) Pneumobacilli; (*e*) *M. tetrageni.*

In two instances the infection was of a mixed nature (*Cases* 3, 4). In these two cases the organism determining the clinical type of the infection was the bacillus of gas gangrene, accompanied in the former by a streptococcus, which predominated, and in the latter by *M. tetragenus.* In seven cases a pure streptococcus was found (*Cases* 5–11). In two further cases (*Cases* 12, 13) the infecting organisms were respectively *B. œdematis maligni* and a pneumobacillus. In four instances the bacillus of gas gangrene was found: two were pure cultures (*Cases* 1, 2), and two, as already stated, were mixed with other organisms.

2. *The ability of similar organisms, circulating in the blood in the living state, to produce diverse clinical pictures,* is a characteristic feature of streptococcal infections.

3. *The presence of living organisms in the blood without the production of serious manifest symptoms,* is of great importance. The discovery of this very interesting fact was made during the routine examination of the blood in a series of patients with infected gunshot wounds, many of them cases which at no time gave rise to any apprehension as to their issue, and which, owing to their comparatively innocent nature, aroused no suspicion of their true clinical character. Particularly interesting in this respect is a type of septicæmia produced by the bacillus of gas gangrene, causing a more or less characteristic symptom-complex, mild, as a rule, in its clinical progress, and, in all cases in one series, terminating satisfactorily. This type will be considered at greater length later. The streptococcus, strangely enough, whilst capable of producing the most virulent of infections, may act very mildly. Indeed, its presence in the blood has been found to be compatible with an

almost normal state of health, a rise of temperature, often of modest dimensions, being the only clinical evidence of the infection.

Clinical records, in so far as such have a bearing upon the course of the disease and the treatment adopted, together with a full temperature chart of each case, are appended to the paper. This has been done with a view to permit of the formation of individual opinion, and to relieve the authors from generalizing in the absence of adequate data.

In all, 29 bloods have been examined. In 13, positive results were obtained, a percentage of 44·7. Of these, 11 were pure cultures and 2 were mixed. In the following table the various types of infection are indicated, together with the number of cases of each type :—

Predominating Organism	Accompanying Organisms	Cases
1. *B. perfringens* ..	None	2
	Streptococcus	1
	M. tetragenus	1
2. Streptococcus ..	None	7
3. *B. œdematis maligni*	None	1
4. Pneumobacillus ..	None	1

The predominating organism in each case has been considered as the cause of the disease, a position of secondary importance having been allotted to the accompanying organisms, when present, from a clinical and therapeutic point of view. Whilst the justice of this discrimination may be open to question bacteriologically, it has certainly been upheld clinically. To this generalization *Case* 3 is an exception, streptococci predominating, whilst the disease took on the type of an infection by the bacillus of gas gangrene.

The deaths in all types combined has been 5, an encouragingly low figure. In the following table are indicated the end-results of the 13 cases cited :—

Type of Infection	Cases	Recovered	Died
1. *B. perfringens* ..	4	3	1
2. Streptococcus ..	7	5	2
3. *B. œdematis maligni*	1	—	1
4. Pneumobacillus ..	1	—	1

The fatal issue in the case of *B. perfringens* septicæmia was due to tetanus, which supervened on the twentieth day of the disease. At the time when this complication set in, the temperature had been normal for some days, the general state of health was extremely satisfactory, and the symptoms characteristic of the primary infection had completely disappeared. Similarly, in the one case in which the pneumobacillus was the infecting organism, the

general condition had improved considerably: a copious secondary hæmorrhage produced a fatal issue. In these two cases the hope that the infection had been overcome was firmly established, and the presumption is justifiable that a cure in each would have been realized had not unfortunate complications arisen. Unhappily, however, the evidence of blood examination is lacking.

1. **Septicæmia due to the B. perfringens of Welch.**—Greatest interest attaches to septicæmia produced by the bacillus of gas gangrene (*B. perfringens* of Welch). Of this, three definite clinical types were observed, totally differing in their expression and their method of termination. They are: (*a*) A fulminating type, with an emphysematous gangrene rapidly spreading directly from a local focus, accompanied by hyperpyrexia, profound toxæmia, and a terminal septicæmia; (*b*) A fulminating type, without gas formation locally, and accompanied by a subnormal temperature; (*c*) A mild type, with gas production locally, mild constitutional reaction, and, as a rule, a favourable issue.

a. In the first type there is an emphysematous gangrene rapidly spreading directly from a local focus, a spread of such alarmingly rapid proportions, of so fulminating a character, that one often feels curiously impotent to arrest its progress. We have all witnessed this short-lived clinical drama from time to time, and recall vividly the foul nature of the wound, the extraordinary development of a thin, offensive, dark-brown discharge, often necessitating a two-hourly change of dressings, and the advancing and rapidly increasing edge of crepitation and tympanicity. We recall the drawn and anxious expression of the patient's features, the death-like pallor of the skin, the excessive activity of the sweat glands, the dilated pupils, the distressing air hunger, the hyperpyrexia, the rapid, running pulse, and the alertness of the mental faculties. We are confronted in such cases with a profound toxæmia, complicated in its terminal phases with a septicæmia. Blood examinations have been conducted in four cases of this class. In two they were negative; in a third the bacillus was recovered from the blood; in a fourth a streptococcus was found. Unfortunately the notes on the third case have been mislaid, and one hesitates to rely upon memory for clinical details, except to state that the bacillus was found in a specimen of blood taken a few hours before death. The fourth case, which is included under the streptococcal type, was a rapidly spreading emphysematous gangrene of the arm: a streptococcus was found in a specimen of blood taken immediately before amputation; six days later examination was negative.

b. The second type of septicæmia produced by gas gangrene is as peculiar and interesting as it is rare. A description of a case which we have had in this hospital will suffice to bring out its characteristics:—

Pte. A. was admitted in April, 1916, suffering from a severe gunshot wound of the soft tissues of the right thigh inflicted forty-eight hours previously. Prior to admission the wound had been excised and counter-incisions made for drainage. There was very little discharge, practically no swelling, and no smell. The wound was remarkably free from sloughs; the exposed muscles were pale, dry, and friable. The counter-openings were exactly similar to post-mortem incisions—there was no

reaction whatsoever, no discharge, and the tissues were soft, putty-like, inelastic, and painless. There was no gas. The general state of the patient was remarkable —widely dilated pupils, cold dry skin of a deathly pallor, air hunger calling into action the extraordinary muscles of respiration, a temperature too low to record, a pulse too rapid to count, and a very noticeable placidity of mind and feature. Death supervened within twelve hours.

At the post-mortem, six hours later, gas was found in the spinal cord, on the surface and in the substance of the brain, and in the liver. The picture was that of a hæmorrhage, for which indeed an examination was made on admission.

Unfortunately there is no note of a blood examination having been made.

The type of wound described in this class is one to which we have given the name 'cadaveric.' More concerning its clinical features, progress, and pathology will be said in the discussion of septicæmia produced by the streptococcus.

c. The third type, of which four illustrative cases are given (*Cases* 1–4), in which the bacillus of gas gangrene was found circulating in the blood, is an interesting and distinct pathological entity, differing from the first two very markedly. Such patients appear to be rarely in a serious condition, certainly never so ill as to lead one to suspect the true clinical character of the disease. The wound is usually foul, presenting all the appearances of one grossly infected with *B. perfringens* and the organisms which usually accompany it. There is a foul discharge, copious in amount, and containing bubbles of gas. There are stringy, œdematous sloughs, which leave a bleeding surface on removal. There is a marked reaction of the surrounding parts, with pain, swelling, œdema, and slight crepitation. There may be a spreading cellular gangrene of the subcutaneous tissues. Constitutionally, the patient reacts in a characteristic manner. The skin is warm, dry, and of a peculiar dirty-yellow colour, and there is a slight icteric tinge of the conjunctivæ. The tongue is dry and furred, and the breath is foul. The appetite is gone, thirst is never troublesome, and the bowels are confined. Temperature and pulse are slightly raised. Mentally, such patients are typical : they are heavy, stupid, and somnolent. This state of torpidity of mind and function lasts until the blood is sterile, the healing of the wound in the meantime being in no way adversely influenced. In the four cases described, no apprehension as to the issue arose, and nothing beyond the usual wound treatment was called for. The recovery from the infection is gradual, although its entire duration, provided the source of absorption receives adequate attention, is short-lived.

One is justified in assuming that many cases of the kind escape detection because of the mild nature of the infection. Moreover, it would appear that during the course of acute infection in the wound such a complication may supervene and be rapidly overcome. Although such an assertion cannot be substantiated by clinical records, one has frequently noticed during the acute stage of a wound the establishment of a general state such as is described above, lasting for a day or two, and then subsiding. The belief that this may be the case receives support from the fact that during these intermissions there is a recrudescence of wound infection. The bacteriology of the discharge and of the blood in this type of septicæmia is indicated in the accompanying table (pp. 402, 403). Metastasis has not been observed.

2. **Septicæmia due to the Streptococcus.**—In our series of cases the streptococcus has been found in the blood in 53·8 per cent. As a rule it appears in pure culture. In one instance (*Case* 3) it was mixed in preponderating numbers with the bacillus of gas gangrene, but the clinical expression of the infection resembled more the *B. perfringens* type. For this reason this case has been included in the previous class, although one cannot overlook the possible extent to which it was influenced by the presence of a streptococcus.

Streptococcal septicæmia presents many interesting features. One has been in the habit of looking upon an infection of this nature as exceedingly serious, placing the life of the patient in extreme jeopardy. Whilst this may be the case, it is by no means always so. In fact, the infection may be—one might almost say is generally—mild, running a benign course, and often terminates favourably without the employment of any special measures directed to its subjugation. It would appear that a blood infection by this organism may arise during the clinical course of wound suppuration, evidence itself in the mildest of fashions, and then subside without seriously affecting the progress of the case. That this can happen is capable of clinical proof; but in what percentage of cases it really occurs requires further investigation. Inclination towards the belief that it is frequent is very strong, and there is a decided temptation to suggest that many temperatures for which no cause can be found locally in the wound may be explained by a blood examination. So much has one the courage of one's convictions, that the blood of all cases in which no satisfactory explanation for temperature disturbance is discovered, is subjected to a cultural investigation.

Another interesting feature of septicæmia in general, although it has been most clearly demonstrated in the streptococcal type, is the nature and extent of the focus of absorption. Naturally one would anticipate, and correctly so, a greater liability to blood infection the more serious the wound and the less the resisting power of the patient. Nevertheless, the focus may be extremely small and apparently trivial. In one instance, for example (*Case* 10), there were two wounds in the thigh, each no larger than a florin, and extending just through the deep fascia into the superficial layers of the subjacent muscle: wounds in which the drainage was perfect, in which there was no retention of discharge, and in which the infection was of a mild nature. In two others (*Cases* 7, 8) the wounds were also of a slight nature, yet a fulminating and rapidly fatal streptococcæmia supervened.

The measure of the resisting power of the patient, apart from all other conditions, appears to be an important factor. This may be naturally low, or may have been reduced by exposure and privation. In several of our cases there is a history of 'lying out' for periods extending from two to ten days, periods during which the patients were deprived of the ordinary means of sustenance.

It has been possible, from a clinical aspect, to classify into three distinct types the seven cases of streptococcal septicæmia we have had, individual examples of each resembling one another very closely, and differing only in detail. These may be stated as follows: (*a*) An acute type, characterized by hyperpyrexia and delirium, rapid in its progress, and ending fatally;

examples of this type are *Cases* 7 and 8. (*b*) A chronic type, with elevation of temperature, profound anæmia, and great emaciation, running a protracted course, and terminating favourably; *Cases* 5 and 6 are examples. (*c*) A mild type, with few clinical manifestations; *Cases* 9 and 10 are instances.

a. The acute type, of which two examples are given, presented as its most noticeable features delirium and hyperpyrexia. Delirium in the former case was of the muttering type; hysterical in the latter. In both it lasted for the duration of the disease. There was a marked tendency to diarrhœa; loss of weight was not observed until during the closing days. In neither were the wounds grossly infected; they were superficial, thoroughly drained, and pursued an eminently satisfactory clinical course. The process of healing was in no way interfered with. In the notes of one, the clinical report was briefly stated thus: "Wound almost healed; patient dying." Both developed extra-articular metastasis, chiefly of the abortive type. In one there was an embolus of the choroidal vessels. Treatment, which will be dealt with later, was of no avail.

b. The chronic type, characterized by profound anæmia and progressive emaciation, is of very great interest. The course of the disease in the two examples cited was very protracted. In contradistinction to those of the acute type, one observed a moderate disturbance of temperature, entire absence of delirium, freedom from metastasis, and the very marked influence the general infection seemed to have upon the progress of the wounds. Anæmia is profound, and emaciation extreme. Diarrhœa may be troublesome. Whilst there is little tendency to metastasis, there is a decided proclivity to abscess formation in relation to the wounds, should they be multiple.

The appearance of the wounds in this type of streptococcæmia is remarkable. We have described them as 'cadaveric.' This description applies equally well to the general condition of the patient, which, so far as reparative processes are concerned, is inert. The original wound in this stage is, as a rule, extremely dirty, being covered with grey, stringy, sloughing material which is but loosely attached and does not leave a bleeding surface on removal. There is considerable involvement of fascia where this is exposed, necrosis of this tissue often extending far beyond the limits of the wound. The structures around are peculiarly soft, putty-like, and inelastic. There is an entire absence of reaction. The absence of pain is a prominent feature; such wounds can be manipulated in quite a gross fashion without any response on the part of the patient. Where excision or counter-incisions have been practised, probably some days before, the appearance is such as is observed in an incision in a cadaver. One has the impression that the incision has just been made. There is, however, no evidence of there having been any oozing; the skin is soft and doughy, and the muscles are pale and dry, the individual fasciculi standing out plainly. Where sloughs are present, there is a moderate amount of a thick, foul discharge. Once these have been cut away, the discharge ceases, and the exposed tissues remain absolutely inert.

This stage may last days—or weeks, as in *Case* 6, where the duration was one month; on Feb. 10 the wounds of this patient resembled in detail their condition on Jan. 10; not a single granulation was to be seen. During this

time there was a tendency to a slow necrosis of tissues badly supplied with blood, such as tendons and fascial coverings of muscles. There was, moreover, in the case of small penetrating wounds, a proclivity to abscess-formation. These abscesses were peculiar, in that they were not painful and that their contents were under very low tension. The walls of such cavities were the unchanged tissues, which had been pushed aside to make room for the accumulating pus. In their depths one perceived muscle bellies pale and inert, standing out as if they had been dissected. Drainage proved unnecessary, as, after evacuation, no further discharge took place, the walls approximating themselves, but exhibiting no tendency to unite.

Resolution in such wounds, when it does take place, may do so with surprising suddenness and rapidity, complete healing being established in a short time. This change is synchronous with an amelioration in the constitutional state, which, in the meantime, has been one of profound anæmia, progressive emaciation, and apathy.

The cadaveric type of wound is not peculiar to streptococcæmia. It has been observed in other forms of septicæmia and toxæmia. It has been referred to in the *B. perfringens* type. It must be looked upon as an arrest of the process of healing, resulting from a profound degree of infection.

The general bacterial wound flora is, as a rule, fairly consistent. We find streptococci, staphylococci, *B. pyocyaneus*, and diphtheroids. The last are the most interesting, and frequently form the predominating organism, especially in wounds about the lower extremities. They are indistinguishable from involution forms of the true Klebs-Löffler bacillus. They are curved, have bulbous ends, and show segmentation of the body. Some exhibit distinct beading, and all stain with Gram. In only one instance has a diphtheroid been encountered which stained with Neisser. These organisms appear to be saprophytic in character. They are rapidly overcome in culture by others present, so that on first subculture it is unusual to find any. Up to the present we have been unable to isolate these organisms in pure culture. When the wound passes from the cadaveric to the healing stage, the diphtheroids at once disappear.

The condition of the pus cells in cadaveric wounds is sometimes interesting. In the majority of cases the cells show degenerative changes, with fragmentation of the nuclei and vacuolation of the cytoplasm. Rarely they are exceedingly well formed, with the perfection of the normal polymorphs of the blood. Phagocytosis is slight or absent. In one instance, however, the pus cells were packed with organisms, resembling the appearance seen in gonococcal pus. In the healing stage of these wounds phagocytosis is extraordinarily active.

c. In the mild type of streptococcal septicæmia there is very little departure from the normal state of health. Sleep is undisturbed, the appetite is excellent, and the general state remains satisfactory. It may be hard to find any clinical manifestations of the disease, beyond a disturbance of temperature. This, however, may be considerable, reaching 102° or 103° at night. Although it may be continued for some time, it appears to have little effect on the patient. Amongst other symptoms, one has noticed during the course of the disease a slight degree of emaciation, periodic attacks of diarrhœa of

short duration, drowsiness, and, in one case, very mild delirium lasting two days. The healing of the wounds may or may not be influenced; there may be a tendency to retardation. The disease has, therefore, certain resemblances to the chronic type above described, of which it may be considered a mild form.

Two examples of this mild type are given, *Cases* 9 and 10. The former is rather interesting. There were multiple shrapnel wounds involving seven joints: both shoulders, both elbows, both wrists, and the right ankle. On admission, all the wounds were in a perfectly satisfactory state and all in an advanced state of repair. A continued temperature led to examination of the blood, in which a long streptococcus was found in pure culture. The subsequent progress was uneventful, no special measures to combat the septicæmia being called for. It is exceedingly interesting to note that this patient, during the whole period of blood infection, ate well, slept well, and always felt in the best of condition.

The latter case (*Case* 10) is exceedingly interesting. Although the patient is still under observation in this hospital, the progress of the disease up to the present is sufficient to reveal the fact that during the period of wound infection there may be periodic absorption of the streptococcus into the blood. The patient in question was wounded on April 27, 1917. Upon admission, May 3, one noticed slight anæmia and pronounced drowsiness. The wounds had a very inoffensive appearance, and did not exceed an inch and a half in their longest diameter, extending for a short distance into the muscles of the thigh. They were discharging a moderate amount of thick yellow pus, drainage was free, and the tissues around were soft and painless. Such granulations as had formed were rather pale and œdematous. The Carrel treatment had been employed prior to admission. The temperature was 97°. On May 6 it rose to 103°, and on the following day to 103·8°, becoming normal again on May 11. During this interval a streptococcus was isolated from the blood. The patient was uncomplaining during this interval; he ate well, and felt well. There was a tendency to drowsiness, and on the night of May 6, when the temperature was 103·8°, he had mild delirium. On May 13 the blood was sterile. The after-progress is interesting: For six days he appeared to be in a normal state of health. On May 17 the thermometer again registered 103°, drowsiness recurred, and on the following day a streptococcus was again isolated from the blood. He has had one attack of diarrhœa. At the time of writing, May 25, the general state of his health is satisfactory. His wounds were thoroughly explored, but no cause for the re-absorption could be discovered. All possible sources of infection have been investigated and found negative. One must at present, therefore, conclude that the initial focus of the infection was the wound. The case is interesting, in so far as it may, upon investigation, throw some light upon unexplainable temperatures occurring during the clinical progress of a wound.

3. **Septicæmia due to the Bacillus of Malignant Œdema.**—This has been extremely rare. We frequently meet with wounds in which the bacillus is present, often in very considerable numbers, but only in one instance (*Case* 12) has it been found in the blood. This case was rapidly fatal, death

occurring about twelve hours after admission. There were several small penetrating wounds in the posterior aspect of both thighs, discharging a very foul and copious, thin, blackish-brown fluid. The wounds were covered with coal-black adherent sloughs. On admission, gangrene had commenced in the left foot; before death it had reached half way up both thighs. From the discharge the bacillus of malignant œdema, the bacillus of gas gangrene, and a streptococcus were grown. The blood for cultural examination was withdrawn six hours before death. The temperature, which was 102° on admission, became subnormal four hours later, and remained so until the close. At no time was the pulse countable. Up to within a few minutes of death there was a most remarkable lucidity of mind. The patient became sensible of his approaching dissolution, and insisted upon writing to his wife. This he did, two hours before he died. Post mortem, there was extensive gangrene of the muscles of the lower extremities, intense inflammation of the walls of the larger arteries, and widespread venous thrombosis.

A second case, not mentioned in the series, might be included here. It was that of a patient with a very extensive wound of the thigh, of a typically cadaveric nature, from which the bacillus of malignant œdema was grown in almost pure culture. He had symptoms of an intense toxæmia. Examination of the blood was negative. Death occurred at the end of four days. Profound anæmia and rapid emaciation, with a subnormal temperature, were the most pronounced clinical manifestations. Delirium was not present until a few hours before death.

4. **Septicæmia due to the Pneumobacillus.**—This case (*Case* 13) is rather unique. There was a perforating wound of the thigh, with a fracture of the ramus of the pubis. The wound was foully infected, and contained the bacillus of gas gangrene in very large numbers. The patient was profoundly anæmic on admission, although he had not lost much blood. During the whole course of the disease the temperature remained elevated. Syncopal attacks were frequent, and at all times the patient complained of great weakness. The slightest exertion caused most alarming symptoms. Two or three days before death, which followed rupture of an artery, the general condition of the patient had improved considerably, and one had very strong hope of a favourable issue. Although unsupported by cultural proof, it is justifiable to assume that in this case the infection had been overcome before death occurred.

TREATMENT.

Treatment naturally divides itself into local and general. It is unnecessary to indicate what is necessary for the local focus. The ordinary principles of wound technique—the removal of sloughs, the opening up of tracks, and the institution of thorough drainage—are obviously called for. In the case of cadaveric wounds, nothing seems to be of any avail: the treatment of the local condition is that of the general state. One word of caution, perhaps, should be given. Such wounds must be kept moist, in view of their natural dryness. If permitted to become desiccated, large areas of necrosis are the result.

TABLE OF CASES OF SEPTICÆMIA.

Case No.	Blood Culture		Blood Count			Pus from Wound	Metastasis	Result
					per cent			
1. B. PERFRINGENS TYPE.								
1	18.11.16. 27.11.16.	*B. perfringens*, with hæmolysis Sterile	R.B.C. 3,480,000 Hb. 75 per cent W.B.C. 16,800	Polymorphonuclears Lymphocytes, large ,, small	78·8 7·4 13·7	Streptococci Staphylococci *B. perfringens*	Nil	Cured
2	16.11.16. 30.11.16.	*B. perfringens*, with hæmolysis and gas Sterile	R.B.C. 3,160,000 Hb. 60 per cent W.B.C. 15,600	Polymorphonuclears Lymphocytes, large ,, small	71·6 9·4 18·8	Streptococci Staphylococci *B. pyocyaneus* *B. perfringens*	Nil	Cured
3	25.10.16. 6.11.16.	*B. perfringens* and streptococci Sterile	R.B.C. 2,280,000 Hb. 55 per cent W.B.C. 15,600	Polymorphonuclears Lymphocytes, large ,, small Eosinophils	73·5 12·0 14.0 0.5	Streptococci *B. perfringens* *B. Hibler IX*	Nil	Cured
4	9.11.16.	*B. perfringens* and *M. tetragenus*, with gas and gelatinization of medium	R.B.C. 3,200,000 Hb. 55 per cent W.B.C. 11,000	Polymorphonuclears Lymphocytes, large ,, small Eosinophils	79.0 10.0 10.0 1.0	Streptococci Staphylococci *B. pyocyaneus* *B. perfringens* *B. Hibler IX* *B. œdematis maligni*	Nil	Septicæmia cured. Died of tetanus.
2. STREPTOCOCCUS TYPE.								
5	25.9.16. 6.10.16. 27.10.16.	Sterile *Str. longus* Sterile	R.B.C. 3,080,000 Hb. 60 per cent W.B.C. 12,200	Polymorphonuclears Lymphocytes, large ,, small Eosinophils	72.0 9.0 18.0 1.0	Streptococci Staphylococci	Pus in left hip-joint	Cured
6	16.1.17. 2.2.17.	*Str. longus* with [illegible] Sterile	R.B.C. 3,200,000 [illegible]	Polymorphonuclears	79.2	Streptococci	Nil	Cured

8	25.10.16. 4.11.16.	*Str. longus* *Str. longus*	R.B.C. 3,300,000 Hb. 60 per cent W.B.C. 7,000	Polymorphonuclears 76·4 Lymphocytes, large 8·2 ,, small 15·0	Staphylococci	Extra-articular embolus in choroidal vessels	Died
9	1.10.16.	*Str. longus*	—	—	—	Nil	Cured
10	10.5.17. 14.5.17. 17.5.17.	*Str. brevis* Sterile *Str. brevis*	—	—	Chiefly streptococci	Nil	Still under observation
11	7.5.17. 13.5.17.	Streptococcus Sterile	—	—	*B. perfringens* Streptococci	Nil	Cured

3. B. ŒDEMATIS MALIGNI TYPE.

12	15.11.16.	*B. œdematis maligni*, with hæmolysis and slight gas	—	—	Streptococci *B. perfringens* *B. œdematis maligni*	—	Died

4. PNEUMOBACILLUS TYPE.

13	8.12.16.	Pneumobacillus	W.B.C. 18,400	—	—	Septic broncho-pneumonia, both lungs	Died from hæmorrhage

On general treatment one cannot be dogmatic, as many of the cases have got well without any. In others, again, several methods have been exhibited, thus making it difficult to ascribe to any one remedy a specific action. For that type of *B. perfringens* septicæmia described above, general treatment is, apparently, unnecessary, the opsonic power of the blood being quite adequate to cope with the infection.

In other cases, four different methods have been employed: (1) Intravenous saline; (2) Intravenous eusol; (3) Blood transfusion; (4) Autogenous vaccines.

If asked to dogmatize, which one is very unwilling to do, intravenous eusol should be given the place of honour. One says so without definite proof, but, at the same time, fully appreciative of its remarkable stimulating powers and of the improvement which, on occasions, has seemed to follow its use. About one dozen of such infusions have been given, the dose in each instance being 100 c.c. of a 0·5 per cent solution. In no case have any untoward symptoms, except perhaps a rigor, arisen. Its stimulating power exceeds that of saline, for which reason its employment in other cases than blood infections may prove of value. In two cases of streptococcæmia (*Cases* 7, 8) its use was discouraging. It would be unfair, perhaps, to ignore its value in *Case* 6, although one must not lose sight of the fact that in this instance saline infusion and blood transfusion were also employed. One is further inclined to believe that a similar result would not have been secured without its use; or at any rate one can quite plausibly ascribe to its stimulating power the salutary effect it had, at a time when the patient's life was despaired of. The case in question resembled clinically *Case* 5, in which vaccines failed to convince one of their value. Of blood transfusion one can say little, owing to lack of experience. Its employment should not be undertaken lightly, as exceedingly alarming symptoms may arise.

CONCLUSIONS.

The conclusions at which one has arrived from a study of these few cases of septicæmia are: that blood infection occurs more frequently in patients suffering with gunshot wounds than is usually supposed; that this infection may be due to a diversity of organisms; that the clinical manifestations of such a complication may be few and trivial; and that the tendency to natural cure is strong.

The following types of cases would appear, from our experience, to be those worth investigating:—

1. Cases presenting wounds grossly infected with the bacillus of gas gangrene, and exhibiting the symptom-complex associated with the third type of septicæmia described above produced by this organism.

2. Cases exhibiting anæmia and emaciation with wounds of the 'cadaveric' type.

3. All cases in which delirium is present, apart from those in which the position of the wound is such that the condition is intelligible.

4. Cases with temperature disturbance not accountable for by the state of the wound.

PARTICULARS OF CASES.

1. B. PERFRINGENS TYPE.

Case 1.—Pte. D., age 18. Wounded Nov. 13, 1916. Missile, high-explosive shell. Admitted Nov. 15. Diagnosis on admission, gunshot wound of right thigh.

Operation before Admission.—The notes state that there was a penetrating wound of right knee-joint, with compound fracture of patella and external condyle of femur. No foreign body was found. Wound excised, capsule sewn up, and a salt pack inserted.

On Admission.—Temperature 100°, pulse 100, dirty-yellow discoloration of skin. Tongue dry and dirty. Felt and looked remarkably well.

On outer side of right knee-joint was a curved incision parallel to and one inch from the outer border of the patella. Narrow track in centre of incision leads down

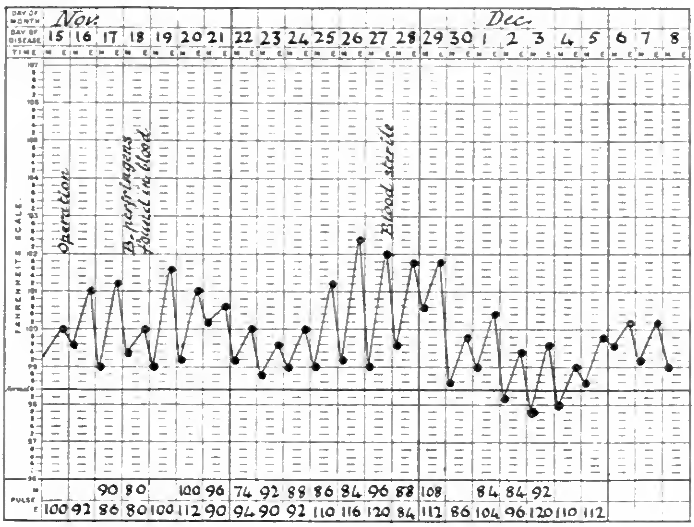


FIG. 325.—*Case* 1. Temperature Chart.

to the external condyle of the femur. No swelling, and very little discharge. The upper anterior surface of the thigh was discoloured, bluish grey, crepitant, and very tender. It was interesting to know that the spread of gangrene in the cellular tissues had been completely arrested distally by the bandage which had been applied firmly round the knee. Proximally the discoloration extended beyond Poupart's ligament.

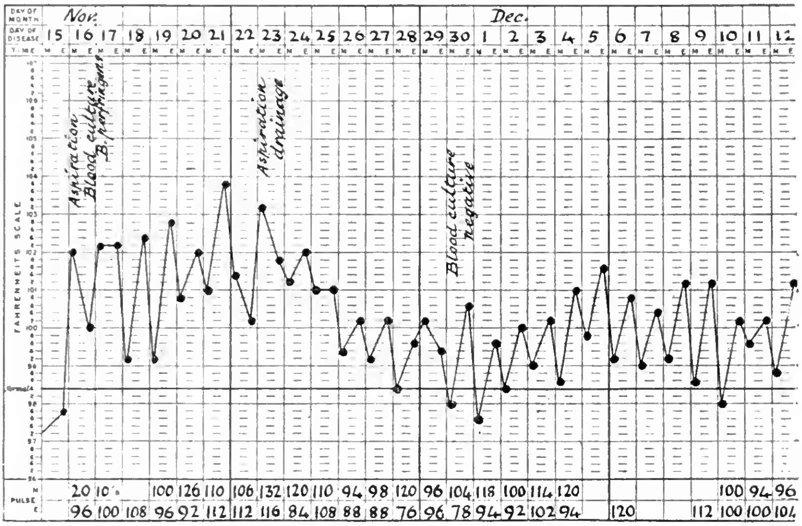
Treatment and Progress.—Multiple incisions in thigh. Foreign body removed, lying deep in muscles of upper part of anterior surface of thigh. Large intramuscular abscess evacuated. Blood culture—*B. perfringens*, with hæmolysis.

Nov. 26: Steady and uneventful recovery. Nov. 27: Blood count—reds 3,480,000, whites 16,800, hæmoglobin 75 per cent: polymorphs 78·8 per cent, large lymphocytes 13·7 per cent, small lymphocytes 7·4 per cent. Blood culture—sterile.

Case 2.—Pte. B., age 32. Wounded Nov. 13, 1916. Missile, high-explosive shell. Admitted Nov. 15. Diagnosis on admission, gunshot wound of both thighs, compound fracture of left femur.

Operation before Admission.—Entry and exit wounds opened freely and drained.

On Admission.—Temperature 97·8°, pulse 120. Patient looks ill. Tongue dry and dirty. Skin shows a dirty-yellow discoloration, with slight icteric tinge of the conjunctivæ. Mentally very dull and apathetic.



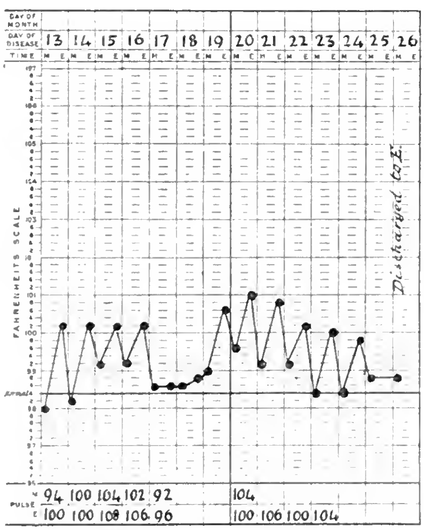


Fig. 326.—*Case* 2. Temperature Chart.

Anteroposterior perforating wound of left thigh, with compound comminuted fracture of femur. Exit wound very foul, discharge copious, and limb very swollen.

Treatment and Progress.—Salt packs removed, sloughs cut away, wounds drained, and limb put up in extension. Blood culture—*B. perfringens*, with hæmolysis and abundant gas formation.

Nov. 23: General state much improved. Abscess on anterior surface of lower fragment incised and drained. Nov. 28: Steady general improvement, copious discharge of yellow pus from wounds. Blood count—reds 3,160,000, whites 15,600, hæmoglobin 60 per cent; polymorphs 71·6 per cent, large lymphocytes 9·4 per cent, small lymphocytes 18·8 per cent. Blood culture—sterile. Dec. 24: Discharged to England.

Case 3.—Cpl. P., age 28. Wounded Oct. 20, 1916. Missile, shrapnel. Admitted Oct. 23. Diagnosis on admission, gunshot wound of left leg, fracture of tibia and fibula. No operation prior to admission.

On Admission.—Temperature 102°. Patient extremely ill, anæmic. Dirty-yellow discoloration of skin, and slight icteric tinge of conjunctivæ. Tongue dry and dirty. Complains of severe pain in left leg.

Perforating wound of the upper third of left leg, with compound comminuted fracture of both bones. Exit wound large, fungating, and lacerated, exceedingly foul, and covered with dark brown, stringy, œdematous sloughs. Dark brown discoloration of skin, extending upwards into popliteal space, crepitant on palpation. Copious discharge, containing gas, oozing from wound.

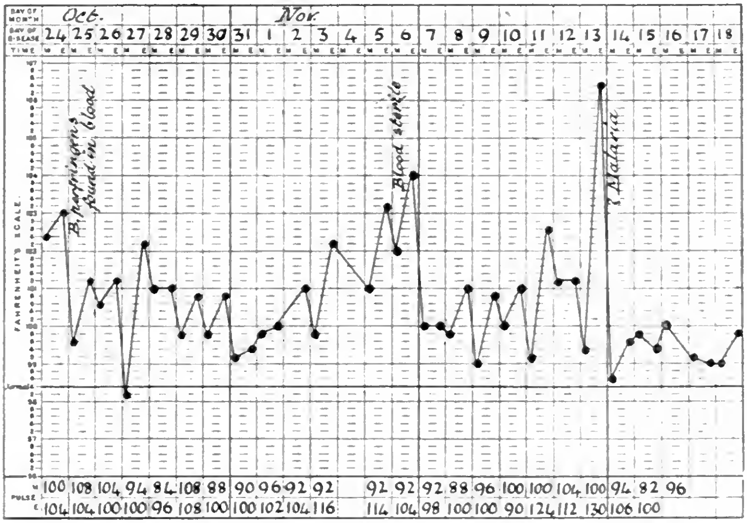


FIG. 327.—*Case* 3. Temperature Chart.

Treatment and Progress.—Oct. 24: Foot dry and cyanosed, cold, pulseless, and insensible. Amputation by transfixion method through lower third of thigh. Blood examination — reds 2,280,000, whites 15,600; polymorphs 73·5 per cent, large lymphocytes 12 per cent, small lymphocytes 14 per cent, eosinophils 0·5 per cent. Blood culture—streptococci and a few *B. perfringentes.*

Oct. 26: Great improvement in general condition. Oct. 30: Improvement maintained. Stump very sloughy. Nov. 2: Improvement continued, stump clean and granulating. Flap approximation commenced. Nov. 5: Stump completely closed. Rolled rubber drain. Nov. 6: Blood culture—sterile. Nov. 10: Rigor, temperature 103·6°, possibly malarial. Nov. 12: Rigor, temperature 104·4°. Stump painless, no swelling, no discharge. Nov. 18: Discharged to England. Stump completely healed.

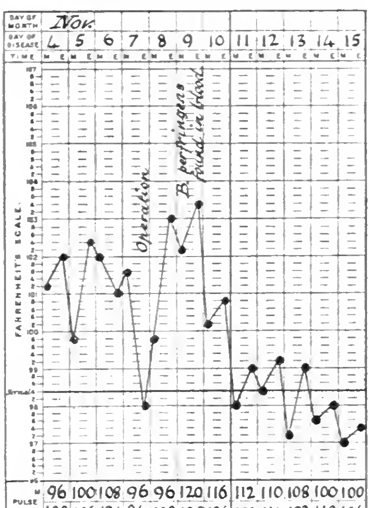


FIG. 328.—*Case* 4. Temperature Chart.

Case 4.—Pte. W., age 22. Admitted Nov. 3, 1916. Diagnosis on admission, perforating rifle grenade wound of left foot.

On Admission.—Patient was pale, and looked very ill. Tongue dry and coated.

Entry wound: Circular in shape, 2 inches diameter, situated on the inner border of distal half of left foot. Exit wound: Large and irregular on the sole and outer side

of middle third of foot, 3 inches in its long axis. The track, which was foul, œdematous, and lined with dark brown, stringy sloughs, passed through the metatarsal region, causing extensive comminution of the first four metatarsals. The discharge was thin, watery, chocolate coloured, copious, and very foul. Bacterio-

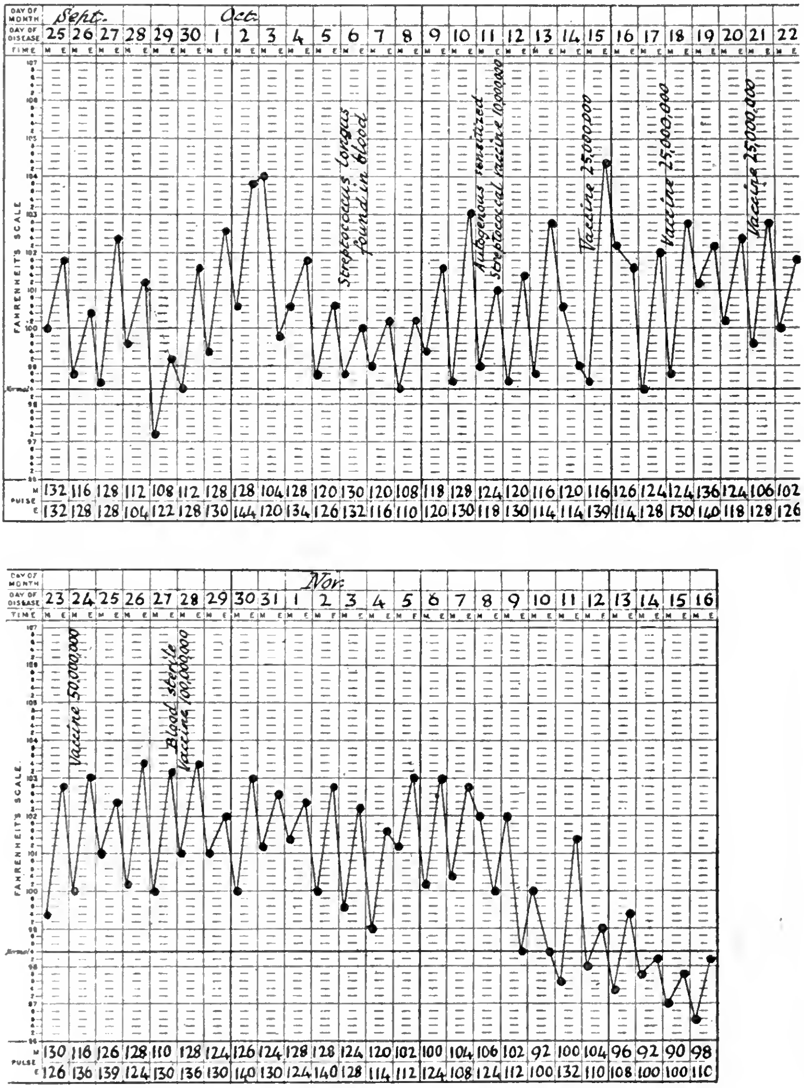


Fig. 329.—*Case* 5. Temperature Chart.

logically, it contained *B. perfringens*, *B. œdematis maligni*, *B. Hibler IX*, free spores, streptococci, staphylococci, and *B. pyocyaneus*. Blood culture—yielded *M. tetragenus* and *B. perfringens*, with gas formation and gelatinization of medium, and subsequent hæmolysis. Blood count—reds 3,200,000, whites 11,000, hæmo-

globin 55 per cent ; polymorphs 79 per cent, large lymphocytes 10 per cent, small lymphocytes 10 per cent, eosinophils 1 per cent.

Treatment and Progress.—Bath for six hours ; eusol fomentations.

Nov. 7 : Temperature ranging between 101° and 103°. Foot became more swollen, with œdema of calf of leg. No crepitation. General condition very poor. Leg was amputated in upper third. For the next two days the temperature remained at 103°, and then came down to normal by crisis. One flap of the stump went gangrenous and was cut away. Nov. 15 : Progress up to this point had been good and rapid ; temperature remained down, and general condition improved markedly ; the stump cleaned up rapidly. Patient here developed tetanus, and died from this complication six days later.

2. STREPTOCOCCUS TYPE.

Case 5.—Pte. M., age 20. Wounded July 1, 1916. Missile, shrapnel. Admitted Sept. 11. Diagnosis, gunshot wound of knee ; amputation.

Operation before Admission, July 5.—Amputation at junction of upper and middle thirds of thigh for gas gangrene.

On Admission.—Temperature 101·6°. Patient very ill, pale, and emaciated. Amputation stump conical, with 2 inches of bone protruding ; exposed surface covered with pale anæmic granulations ; practically no discharge.

Treatment and Progress.—Sept. 16 : Temperature 103° at night. Complains of pain in left groin : no swelling, but slight tenderness. Movements of hip-joint exceedingly painful. Dry arthritis of hip-joint diagnosed, and limb put up in extension. Sept. 25 : Blood culture—sterile. Sept. 27 : Very troublesome diarrhœa. Oct. 6 : Patient becoming thinner, eats and sleeps badly, slightly jaundiced. Blood culture—*Streptococcus longus.* Oct. 10 : Sensitized autogenous vaccine made, and injections commenced with 10,000,000. Starting pains in left hip-joint at nights. Oct. 14 : 25,000,000 vaccine, followed by marked reaction. Oct. 17 : 25,000,000 vaccine, marked reaction. Pain, tenderness, and swelling around right elbow-joint. Patient very ill. Oct. 20 : 25,000,000 vaccine. Swelling and redness of arm gone. No swelling or pain in left hip-joint. Oct. 23 : 50,000,000 vaccine. Oct. 26 : 100,000,000 vaccine. Oct. 27 : Blood culture—negative. Oct. 29 : Temperature 104°. Slight œdema in left groin. Nov. 11 : Three ounces of pus evacuated by incision above and parallel to Poupart's ligament. Nov. 22 : Incision in right groin healed. General condition much better. Dec. 19 : Discharged to England.

Case 6.—Pte. C., age 22 Wounded Jan. 6, 1917. Missile, shrapnel. Admitted Jan. 10. Diagnosis, gunshot wound of thigh and leg.

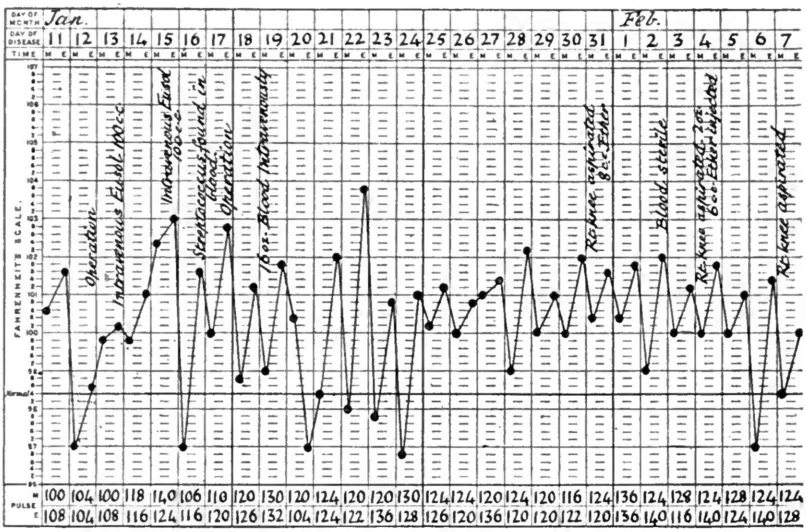
Operation before Admission, Jan. 6.—Wounds excised and drained.

On Admission.—Temperature 100·6°, pulse 100. Patient very anæmic, and looked ill. Slight icteric tinge of conjunctivæ. Tongue dry and dirty. Pulse small and poor.

Two penetrating wounds on inner aspect of lower half of left thigh. Track in each case leads directly outwards for 3 inches. Copious discharge of yellow pus. There was an elliptical excised wound 5 inches long, extending deeply behind the tibia. Wound surfaces were covered with stringy, œdematous, dark-brown sloughs. There was considerable necrosis of the intermuscular septa, and a copious foul discharge. There were numerous small penetrating wounds on back, and right thigh.

Treatment and Progress.—Jan. 12 : Operation. Wounds cleaned up, all slough cut away, and Carrel's treatment instituted. Jan. 13 : Wounds extremely foul, and of 'cadaveric' type. Eusol fomentations applied. Jan. 14 : Intravenous eusol, 100 c.c. Jan. 16 : All slough separated from wound ; exposed tissues pale, painless, soft, desiccated, and elastic ; practically no discharge. Blood culture—yielded *Streptococcus longus*, growing more profusely in anaerobic culture, and with distinct hæmolysis Intravenous eusol, 100 c.c., with saline 10 ounces. Jan. 17 : Patient *in extremis*. Exceedingly pale and thin, pulse running and almost uncountable, respirations very shallow, skin cold and dry, slight delirium at times, practically

no discharge from wound. Secondary hæmorrhage from posterior tibial artery; amputation through lower third of thigh. Intravenous eusol, 100 c.c., saline 10 ounces. Jan. 18: Patient still very ill. Citrated whole blood, 16 ounces, injected intravenously. Feb. 10: There has been a gradual and slight improvement in



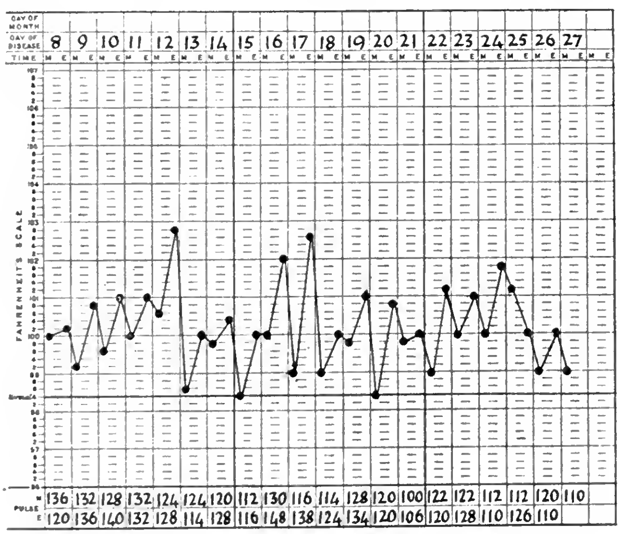


FIG. 330.—*Case* 6. Temperature Chart,

patient's general condition, the wounds remaining in the 'cadaveric' state. Several abscesses developed in connection with wounds of both thighs, and these were opened and drained. Feb. 14: Wounds healthy and granulating. The general condition much improved. Feb. 27: Discharged to England cured.

Case 7.—Pte. C., age 25. Wounded Oct. 20, 1916. Admitted Oct. 24. Diagnosis, gunshot wound of buttock.

Operation before Admission.—Wound excised and drained.

On Admission.—Temperature 102°, pulse 96. Patient mildly delirious, and complaining of pain in right leg and right hypogastrium.

Large excised wound of the right buttock, extending deeply into muscles, moderately clean, and a moderate amount of discharge. Swelling, œdema, and tenderness of middle of posterior aspect of right thigh.

Treatment and Progress.—Slight improvement in general condition; but still delirious. Abscess in thigh extending from buttock wound opened and drained. Syringed and dressed with eusol three times daily.

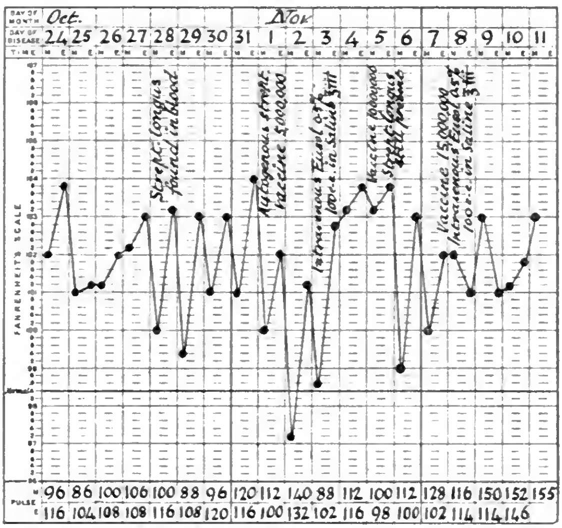


FIG. 331.—*Case* 7. Temperature Chart.

Oct. 28: Blood culture—yielded *Streptococcus longus* in pure culture. Nov. 1: Autogenous streptococcal vaccine, 5,000,000. Wound drained satisfactorily. General state, *in statu quo*. Nov. 3: Intravenous eusol. 100 c.c. Nov. 5: Vaccine, 10,000,000. Blood culture—*Streptococcus longus*. Nov. 7: Vaccine, 15,000,000. Nov. 8: Intravenous eusol 0·5 per cent, 100 c.c. Nov. 11: Patient died.

During the whole course of the disease patient was delirious; he slept and ate moderately well. The progress of the wound was satisfactory. The terminal stages of the disease were complicated by increase in delirium, emaciation, profuse sweating, and incontinence of urine and fæces. No metastases were observed, and a post-mortem was not performed.

Case 8.—Pte. B., age 25. Wounded Oct 5, 1916. Missile, shrapnel. Admitted Oct. 8. Diagnosis, gunshot wound of thigh.

Operation before Admission.—Excision of wounds.

On Admission.—General state fair, tongue clean. Temperature 100°, pulse 70.

Large circular excised wound 2½ inches in diameter, base fairly clean, marked reaction in surrounding skin.

Treatment and Progress.—Steady general improvement for five days after admission.

Oct. 19: Temperature 105°, pulse 88. Does not complain of pain. Wounds satisfactory. Abdomen and chest. nothing abnormal. Oct. 22: Temperature 104·8°, pulse 80. Delirium of a hysterical nature. Oct. 23: Urine examined,

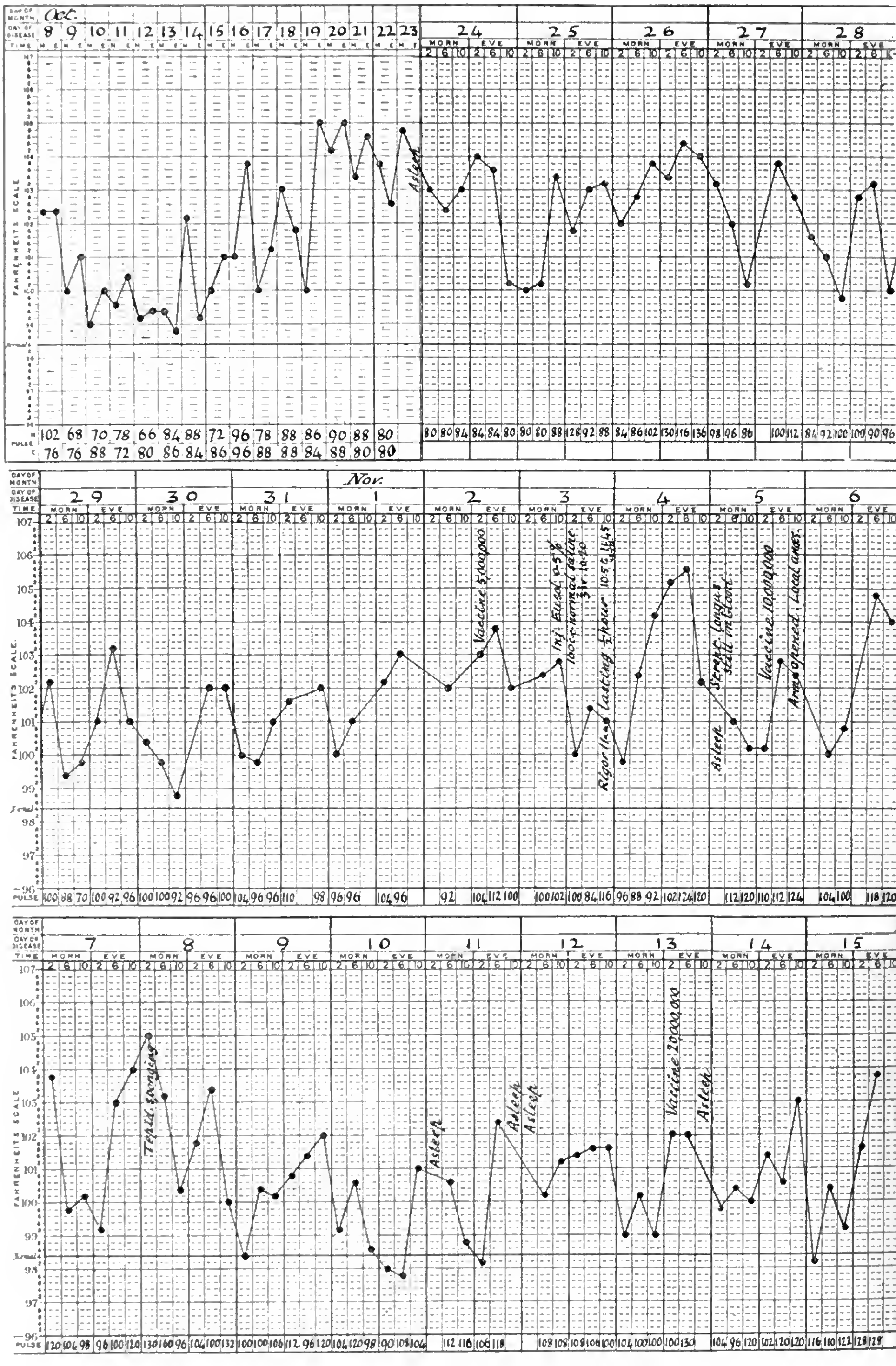


FIG. 332.—*Case* 8. Temperature Chart.

nothing abnormal found. Leucocytosis 7,000. Widal negative. Fæces examined. *B. coli* only found. Heart, lungs, and abdomen normal. Wounds healing rapidly. Oct. 25: *Streptococcus longus* in pure culture found in blood. Delirious during the greater part of the day. Oct. 26: Diarrhœa. Eusol, 100 c.c., intravenously. Oct. 27: Swelling, œdema, and redness round both elbow-joints and left wrist-joint. Oct. 29: Patient getting worse. Nov. 1: Embolus in left choroidal vessels. Nov. 4: Right arm opened and 4 ounces of pus evacuated; no bone or joint involvement. Autogenous antistreptococcal vaccine, 10,000,000, given. Nov. 14: Patient much weaker. Incontinence of urine and fæces. Very free perspiration. Wounds healing. Nov. 15: Patient died comatose.

Case 9.—Pte. W., age 27. Wounded Aug. 29, 1916. Missile, bomb. Admitted Sept. 3. Diagnosis, gunshot wounds, multiple.

Operation before Admission.—Excision of wounds, and drainage. Left shoulder-joint excised.

On Admission.—General condition good.

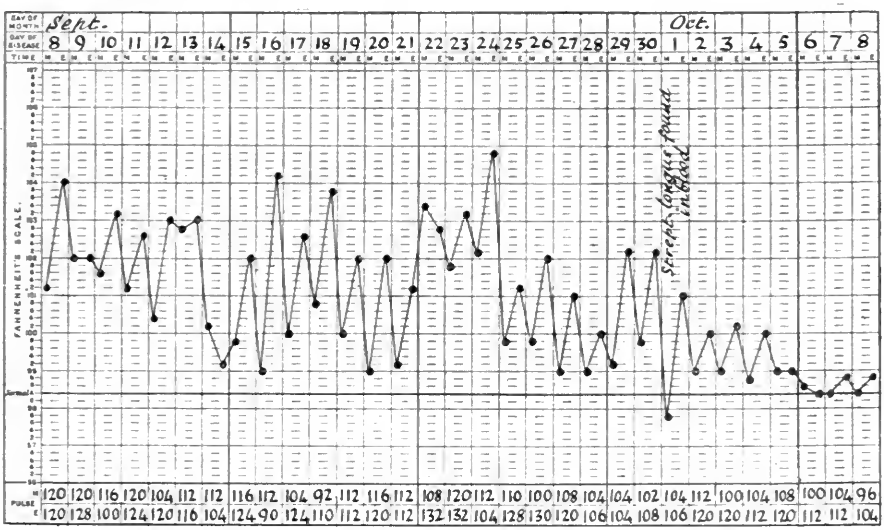


FIG. 333.—*Case* 9. Temperature Chart.

Penetrating wounds of both shoulders, both elbows, both wrists, and left ankle-joint. Wounds were all in a satisfactory condition, and draining well.

Treatment and Progress.—Dressed with eusol three times daily. Apart from temperature, patient's progress was very satisfactory.

Oct. 1: Blood culture—*Streptococcus longus.* Oct. 5: Temperature normal. Oct. 19: Discharged to England.

Case 10.—L.-Cpl. R., age 22. Wounded April 23, 1917. Missile, whizz-bang. Admitted May 3. Patient lay out two days after being wounded.

Operation before Admission.—Wounds had been excised.

On Admission.—Slight degree of anæmia, and a tired expression. Says he feels well. Temperature 98°.

There were two penetrating wounds on the outer side of the right thigh, each about the size of a florin. The track in each invades the superficial layers of underlying muscle only. Discharge moderate in amount, yellow in colour, and thick in consistence. It contains streptococci chiefly. Granulations are abundant, but pale and œdematous.

Treatment and Progress.—May 7: Temperature 103°. Mild delirium and drowsiness. Wounds are still in a callous state. No pain, tenderness, or swelling. Says he feels very well. May 8: Streptococcus isolated from blood. General

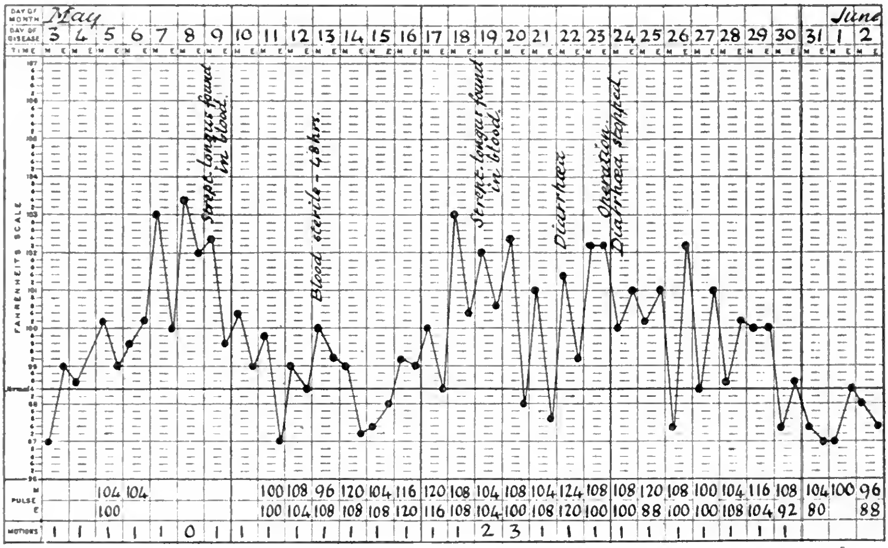


Fig. 334.—*Case* 10. Temperature Chart.

condition of patient quite satisfactory. No special treatment adopted. Wounds *in statu quo.* May 14: Blood sterile. Delirium and drowsiness quite gone. Patient looks well, is not so anæmic, looks and feels well. One wound in thigh almost healed. The other is discharging slightly. May 18: Temperature 103°. More discharge from wound. Patient very drowsy, and not looking quite so well. May 19: Streptococcus found in blood. May 21: Slight attack of diarrhœa. May 24: Wounds explored—very satisfactory. General condition of patient is remarkably good. He eats and sleeps well. His drowsiness has quite gone.

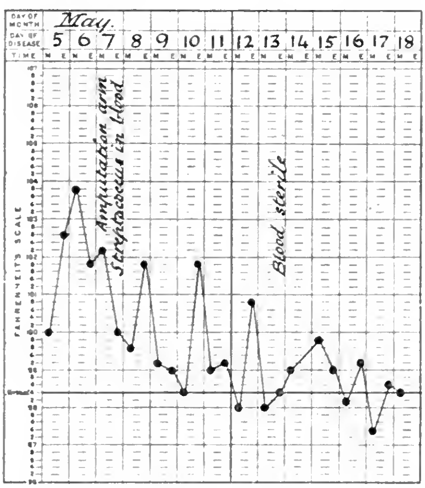


Fig. 335.—*Case* 11. Temperature Chart.

Case 11.—Pte. W., age 25. Wounded May 3, 1917. Missile, machine-gun bullet. Admitted May 4.

On Admission.—Severe perforating wound of right forearm just below elbow-joint, with comminuted fracture of ulna. Discharge copious, and containing bubbles of gas. Arm swollen and œdematous. No radial pulse. Pus from wound contained *B. perfringens* and streptococci.

Treatment and Progress.—May 5: Wound opened up and drained. Hole found in wall of radial artery, which was blocked by septic clot. One and a half inches of artery resected. May 7: Rapidly

spreading emphysematous gangrene of forearm. Amputation through middle of upper arm. Blood culture—streptococcus isolated. Further progress uneventful. Blood sterile on sixth day after amputation.

The blood for investigation was taken immediately before amputation. The general condition of the patient, on admission, very closely resembled that associated with the mild type of septicæmia produced by the bacillus of gas gangrene.

3. MALIGNANT ŒDEMA TYPE.

Case 12.—Pte. J., age 33. Wounded Nov. 13, 1916. Missile, shrapnel. Admitted Nov. 15. Diagnosis on admission, gunshot wound of legs. No operation on admission.

On Admission.—Temperature 102°. Exceedingly ill, pulse almost uncountable; very pale, and slightly jaundiced. Mentally, remarkably clear. Has no pain, feels quite comfortable and contented.

Lacerated elongated wound 6 inches long on outer surface of left thigh just above great trochanter. Several penetrating wounds on posterior aspect of both calves. Wounds extremely foul, covered with black, closely-adherent sloughs, bleeding on removal. An almost continuous flow of thin, dark-brown fluid. Left lower extremity as far as knee was cold, black, and tympanitic. Right foot and lower third of leg black and gangrenous. Skin beyond this as far as knee raised in blebs containing dark-brown putrid fluid.

Treatment and Progress.—Stimulants. Eusol, 100 c.c., intravenously. Eight hours later the gangrene has spread as far as the middle of both thighs. The thermometer failed to register, and the pulse was uncountable. During this time the dressings and mattresses were several times soaked with discharge. Death ensued twenty-one hours after admission. Patient was perfectly conscious until within five minutes of death. Pus contained *B. perfringens* and *B. œdematis maligni*. Blood culture—*B. œdematis maligni*, with marked hæmolysis.

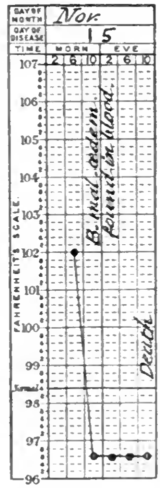


FIG. 336.—*Case* 12. Temperature Chart.

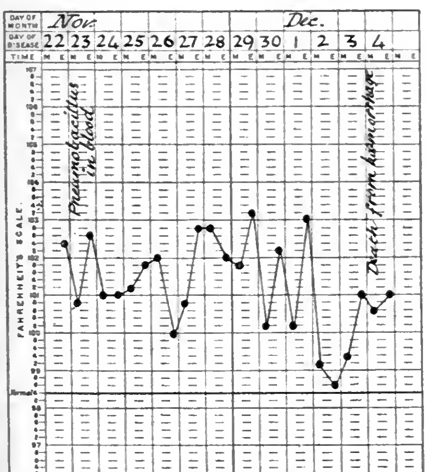


FIG. 337.—*Case* 13. Temperature Chart.

4. PNEUMOBACILLUS TYPE.

Case 13.—Pte. H., age 26. Wounded Nov. 14, 1916. Admitted Nov. 22. Diagnosis, gunshot wound of right groin. Missile, high-explosive shell.

On Admission.—Patient very pale and haggard, slightly cyanosed, but not complaining much of pain: tongue dry and dirty. Temperature 102°, pulse 104.

Entry wound: Circular, 1 inch in diameter, above and external to middle of right buttock. Exit wound: Large and irregular, about 4 inches long, situated in right groin. Extremely foul, and discharging copious foul pus.

There was a patchy consolidation of the right base.

Treatment and Progress.—Nov. 24: Eusol dressing to wound, and stimulants. Secondary hæmorrhage from obturator artery. Artery tied. Large area of gangrene palpated in pelvis through obturator foramen. Area cleaned up and drained.

Counter-incision for drainage immediately above outer half of Poupart's ligament. Intravenous saline, 1 pint, normal horse serum, 10 c.c. hypodermically; calcium lactate, gr. x, three times daily.

Nov. 25: Blood examination—coagulation time, eight minutes; leucocytes 18,400. Blood culture—yielded pneumobacillus. Nov. 26: Examination of sputum—pus cells numerous; gram positive bacilli and streptobacilli predominating organism. Intravenous saline, 1 pint. Nov. 27: Patient very weak and ill; had several syncopal attacks. Nov. 29: Slight general improvement. Right ankle swollen, œdematous, and tender. Wound cleaned. Dec. 2: Great improvement in general state. Dec. 4: Improvement maintained, wounds granulating nicely, practically no discharge. Dec. 5: Secondary hæmorrhage and death.

Post-mortem.—Wounds of entry and exit, and track of missile, were fairly clean; there was some sloughing of the track in the neighbourhood of the pelvis, and the muscles were friable and œdematous. Hæmorrhage was found to have occurred from a branch of the obturator artery. There was a slight fracture of the pubic arch on the upper surface, but no gross lesion anywhere. Both lungs showed a septic bronchopneumonia.

TWO CASES OF SQUAMOUS EPITHELIAL TUMOUR OF THE BREAST.

By RAYMOND JOHNSON, London,
and T. W. P. LAWRENCE, London.

The rarity of tumours of the breast containing squamous epithelium is sufficient to justify the publication of the two cases with which this short communication deals.

Ordinary squamous-celled carcinoma arising in the cutaneous covering of the breast calls for no particular remark. Examples of squamous-celled carcinoma originating deeply in the breast substance are also on record. Such tumours may be supposed to have their origin either in rests, or in a reversion of the glandular epithelium to the original type in which the epithelium of the breast takes its origin (metaplasia).

In the two cases here recorded, the growth presented itself as a definite tumour of the breast, and in each the outstanding histological feature was the presence of squamous epithelium with well-developed prickle cells.

The first case was that of a married woman, age 53, who accidentally discovered a lump in the left breast three weeks before she came under observation.

On examination, a rounded tumour as large as a walnut was present in the upper and outer quadrant of the breast. The nipple was normal, and the tumour, although intimately connected with the breast tissue, was not attached to the skin or deeper structures. There were no palpable glands in the axilla. The tumour appeared to be slightly elastic, and was thought to be a cyst.

It is interesting to mention that three of the patient's sisters had had cysts of the breast. In one, a cyst had been excised; in another, two cysts had been punctured; and in the third, two operations had been performed for multiple cystic disease.

The tumour, on removal, proved to be a solid growth, and was regarded as a carcinoma. The whole breast, with the pectoral muscles and axillary contents, was therefore removed. A year later there was no evidence of recurrence.

Description of Specimen.—The tumour is ovoidal in shape, and measures 5 cm. in its longest diameter. In the fresh state the consistence was moderately firm, and the surface of the section presented an opaque white colour and coarse granular structure. After hardening in formalin, a fresh section of the tumour shows to the naked eye a grey fibrous-looking ground-substance, in which are irregular opaque areas of a yellowish-white colour. The tumour has a well-defined outline, but is intimately connected with the surrounding breast tissue and fat.

FIG. 338.

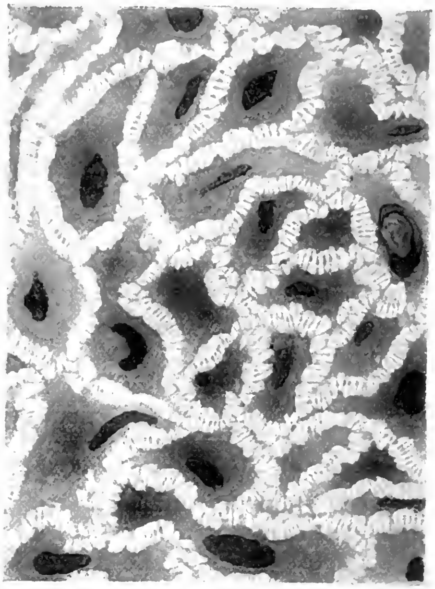


FIG. 339.

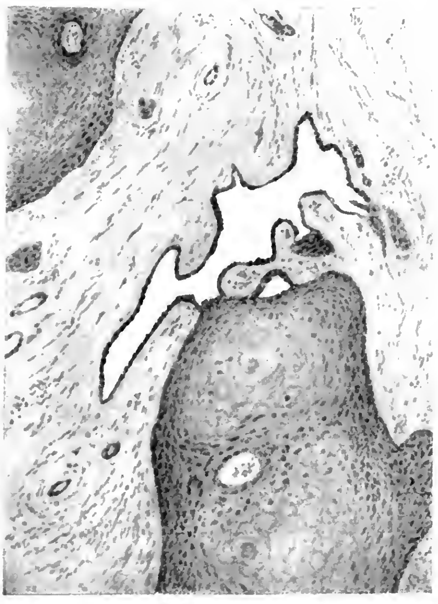


FIG. 340.

FIG. 341.

SQUAMOUS EPITHELIAL TUMOUR OF THE BREAST.

Drawn by T. W. P. Lawrence, F.R.C.S.

The remainder of the mammary gland is atrophied, but otherwise normal in appearance. The axillary fat contains several glands, the largest of which is 1·5 cm. in length and presents a narrow zone of lymphoid tissue around a fatty centre.

Microscopic Structure.—The outstanding feature in the structure of the tumour is the presence of irregular masses of epithelium (*Fig.* 338), the cells of which are in a large measure very perfectly developed prickle cells (*Fig.* 339). In each epithelial mass, the cells which lie next the stroma are small flattened prickle cells. Beneath these is a thick layer of larger prickle cells. Still nearer the centre of the mass is a thin layer of swollen cells in which prickle cells are almost completely absent. These cells stain blue with hæmatoxylin, and some of them contain masses of fine granules. Lastly, the centre of the mass is composed of nucleated squamous cells, staining pink with eosin, and in many places arranged in cell-nests. There is no evidence of degeneration of the cell masses. No structures resembling papillæ are to be seen. Interspersed among these masses are numerous irregular gland-like spaces, lined with irregular spheroidal epithelium in layers of from one to three cells. Some of the spaces contain a structureless or finely granular substance staining pink with eosin. In some places a direct transition of the epithelial lining of these glandular spaces into the masses of prickle cells can be traced (*Fig.* 340). The stroma for the most part stains blue, and is composed of a loose cellular connective tissue; in other parts it is pink, and is composed of bundles of white fibrous tissue containing spindle-shaped nuclei. Scattered through the tumour are small islands of breast tissue, with fat (*Fig.* 341). The stroma around these islands shows a lymphocytic exudation, but no such exudation is present elsewhere. The axillary lymphatic glands removed show no deposit of growth.

A search through the literature of the subject shows that the tumour most closely resembling that now under consideration is one described by Konjetzny (*Beitr. z. klin. Chir.*, 1912, lxxviii). This tumour occurred in a woman, age 34, who was pregnant at the time; it had been noticed for six months, and was situated in the outer part of the right breast. The tumour after removal measured 15 cm. by 8 cm., and consisted of a cyst surrounded by solid growth. Microscopically, the solid part of the tumour showed cell masses consisting of typical stratified squamous epithelium with very perfectly developed prickle cells. Besides these there were small masses of rounded cells, having in parts an alveolar arrangement, and without prickle cells. The axillary glands showed a simple inflammatory hyperplasia. No direct connection of the tumour tissue with that of the breast could be demonstrated, and Konjetzny suggests that the tumour probably had its origin in an early embryonic ectodermal rest.

Small masses of squamous epithelium, sometimes mixed with cholesterin to form cysts, are occasionally met with in tumours having the general characters of fibro-adenoma.

The second case was that of a married woman, age 50, who was admitted into University College Hospital, April 3, 1913, with a tumour of the left breast which had been noticed for four months. An "abscess" formed in the tumour, and, after poulticing, discharged through the skin.

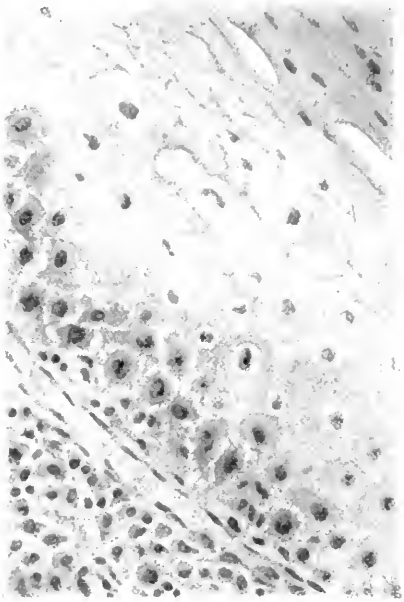


FIG. 342.

FIG. 343.

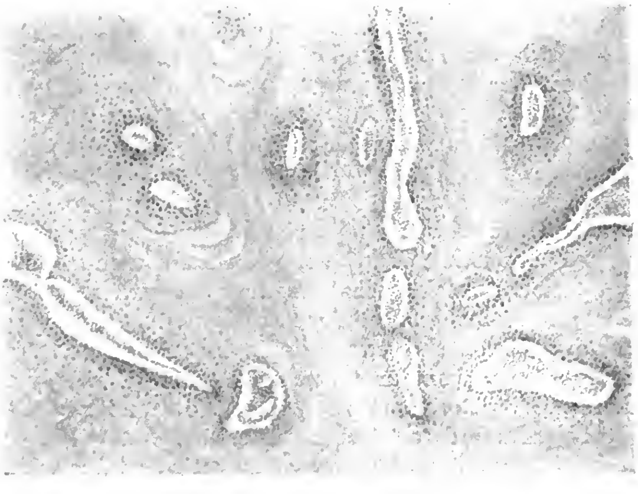


FIG. 344.

SQUAMOUS-CELLED CARCINOMA OF THE BREAST.

Drawn by T. W. P. Lawrence, F.R.C.S.

On admission to the hospital, there was a prominent tumour, 3 in. in diameter, in the upper and inner quadrant of the left breast. The overlying skin was reddened, and the centre had broken down to form a small round ulcer with soft flat base and thin non-indurated margins. From the ulcer a probe could be passed into the centre of the growth for 2½ inches. There was a free discharge of yellow serous fluid. The whole tumour was soft, and the skin, except at the margin of the ulcer, was not infiltrated. The remainder of the breast appeared to be normal, and the tumour was not fixed to the pectoral muscle. Two enlarged hard glands could be felt in the axilla, and another as large as a pea in the poster or triangle of the neck. There were no evidences of secondary deposits in the thorax or abdomen.

The breast, together with the axillary contents and the pectoral muscles, was removed.

Description of Specimen.—A section through the breast, after hardening in formalin, shows that the peripheral part of the tumour, which is intimately connected with the surrounding fat and the remains of the breast tissue, is of a uniform yellowish-white colour, whilst the central part is broken down into an irregular cavity. The tumour extends into the breast for 7 cm. beneath the skin. Superficially the growth extends to the floor of the ulcer above mentioned, and in this situation takes the form of small opaque white strands in the subcutaneous fat. The nipple is separated by 3 cm. from the edge of the growth; it is normal, and beneath it is a small area of breast tissue.

Microscopic Structure.—The tumour is a squamous-celled carcinoma. The epithelium is arranged in masses, in each of which is a central core of loose connective tissue (***Fig.*** 344). The layer of cells immediately surrounding the connective tissue presents the appearance of those of the Malpighian layer of the skin, whilst peripheral to these are gradations passing to horny scales (***Fig.*** 342). In places well-marked prickle cells are present (***Fig.*** 342). The axillary lymphatic gland examined is infiltrated with masses of squamous cells (***Fig.*** 343).

In the second of these two cases we have no doubt that we are dealing with a squamous-celled carcinoma originating in the skin overlying the breast, and with the naked eye it was possible to trace fine lines of opaque growth between the surface of the tumour and the skin itself. The structure of the tumour is in one respect peculiar, in that the epithelial masses, instead of presenting the usual alveolar structure, have retained an exaggerated papillary arrangement, so that these masses in section are seen to enclose a core of cellular connective tissue (***Fig.*** 344).

The true nature of the first specimen is less apparent. Among the reasons that lead us to believe that the tumour is not a carcinoma are: (1) The association of gland-like spaces with the epithelial masses; (2) The abrupt change from the small cubical epithelium of the spaces into the squamous epithelium of the cell masses; and (3) The regularity of the cells of the squamous epithelial masses. Possibly the tumour is allied to those recorded by Wilms, Beneke, and others, in which epithelial pearls are present in fibro-adenomas.

REMOVAL OF A RIFLE BULLET FROM THE RIGHT LOBE OF THE CEREBELLUM; ILLUSTRATING THE SPONTANEOUS MOVEMENT OF A BULLET IN THE BRAIN.*

By GEOFFREY JEFFERSON,

Chief Surgeon to the Anglo-Russian Hospital, Petrograd.

The following case is chiefly interesting as being a good example of the spontaneous movement of a bullet within the brain. Indeed the bullet not only moved, but turned round—spontaneous version.

Fig. 345.—Lateral view of skull. Bullet lies nose downwards and forwards in cerebellum, 3 cm. from os occipitale. The x marks point of entry.

Fig. 346.—Lateral view of skull 19 days later. Bullet now lies nose upwards 1 cm. from os occipitale.

The patient was a Tartar boy, age 18, a chauffeur. He was shot in the head on the afternoon of Feb. 28, 1917, during the Revolution. Judging by the position of the wound and by the course taken by the bullet, the shot was probably fired from a house-top. He was admitted to the Anglo-Russian Hospital in a semi-conscious condition within a few minutes of being wounded. He vomited several times in the first half-hour. The wound was situated 12 cm. above and 1 cm. behind a line drawn vertically upwards from the pre-auricular point. The scalp was shaved and the wound explored, without

* Paper read and case exhibited before the Russian Surgical Society of Pirogov, Petrograd, May 23, 1917.

anæsthesia. The bullet track ran downwards and backwards through the meninges. There was remarkably little splintering of the skull. The bullet was not palpable. The patient was x-rayed the following day, and a rifle bullet was seen to be lying in the right cerebellar fossa. The bullet lay obliquely, with its nose downwards, inwards, and forwards, suggesting that it had been deflected somewhat after entering the skull. It lay embedded some 3 cm. deep in the right lobe of the cerebellum (*Figs.* 345, 347). Considering the serious condition of the patient and the depth of the projectile, it was considered inadvisable to attempt immediate removal. Clinically, the chief localizing signs were nystagmus towards the right, a tendency to fall always towards the right side when made to take a few steps, and right-sided dysdiadochokinesia.

During the ensuing days he gradually improved, and on March 19 fresh x-ray photographs (a stereoscopic pair) were taken preliminary to operation.

Fig. 347.—Antero-posterior view of skull. Bullet lies obliquely in right lobe of cerebellum, its base towards middle line. (Plate made with tube in front, plate behind.)

Fig. 348.—Antero-posterior view of skull 19 days later. Bullet lies almost horizontally, base outwards. (Plate made with tube behind, plate in front.)

It was now seen that the bullet had moved during the nineteen days that the patient had lain upon his back. It had sunk backwards until it was now separated from the inner surface of the occipital bone by barely 1 cm. This general movement backwards had been accompanied by a version of the bullet, so that its nose, which formerly pointed forwards, downwards, and inwards, now pointed backwards, upwards, and inwards (*Figs.* 346, 348), the general lie of the bullet being now horizontal. The bullet had therefore traversed a distance of some 2 cm., and, as will be seen from the plates, its base had gone through a relatively large excursion.

It is unfortunate that the later antero-posterior radiograms were taken from before backwards, the earlier one having been taken in the reverse

direction. However, there can be no doubt about the fact that the bullet has actually moved considerably in this case, though Gamlen and Smith[1] are doubtless right in believing that such movement is often apparent only; due to failure to reduplicate exactly the former position of the head.

On March 24 the bullet was easily extracted from the right lobe of the cerebellum. The upper fibres of the trapezius had to be divided at their origin from the os occipitale, and after removing a disc of bone with a hand trephine, bone was clipped away freely. The lateral sinus was exposed in this procedure, and the dura incised horizontally below it. The bullet was found lying in a shallow abscess cavity, the pus from which proved to be sterile on culture. The patient made an uneventful recovery. Six weeks after operation the only symptom remaining was the dysdiadochokinesia.

At no time was there any disturbance of vision, yet the line of the bullet, had it taken a direct course, must have passed through the right calcarine fissure. My confrère, Professor Poussep, suggested that in view of this absence of visual upset, it is probable that the bullet ran backwards, pierced the left tentorium cerebelli, and then crossed into the right cerebellar lobe. This, I think, is very probably the correct interpretation. A slowly-travelling bullet would easily be deflected by so rigid a structure as the tentorium.

As to the wandering of the bullet, Flourens, it is interesting to recall, found that bullets experimentally introduced into the cerebrum and cerebellum always tended to sink towards the base of the skull.[2] Krause, in his monograph,[3] records a case where a revolver bullet moved a considerable distance (Kugelwanderung) in a few weeks and then came to rest. Vilvandré and Morgan[4] have published a case in which a shrapnel ball apparently rolled round as well as sank backwards.

In general, the movement of bullets in the substance of the brain must, I think, be attributed to a combination of any or all of the following factors :—

(1) The action of gravity, the specific gravity of the bullet being far higher than that of the brain ; (2) Local softening of the brain around the bullet, or abscess formation ; (3) The pulsations of the brain. The twisting or version of the bullet is probably caused by the following :—(1) Unequal softening round the bullet, allowing, for example, its base to sink before its nose ; (2) Uneven distribution of weight in the bullet itself, the posterior half being heavier than the anterior ; (3) The homogeneity of the brain tends to a general and even sinking; but anything which interrupts this homogeneity, such as a leash of blood-vessels, might impede one part of a bullet, and so cause it to turn.

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[1] "Inter-relation between the Radiography and Surgery of Gunshot Wounds of the Head," *Brit. Jour. Surg.*, 1917, July.
[2] Quoted by Rowlands and Turner, *The Operations of Surgery*, 1915, i, 286. London.
[3] *Der Chirurgie des Gehirns*, Berlin, 1909.
[4] "Movements of Foreign Bodies in the Brain," *Arch. Radiology and Electrotherapy*, 1916, June.

SOME ASPECTS OF THE TREATMENT OF INFECTED WAR WOUNDS.

(From the Millicent Sutherland Hospital.)

By Captain O. G. MORGAN, R.A.M.C., Captain F. D. SANER, R.A.M.C., and Temporary Surgeon E. G. SCHLESINGER, R.N.

In any discussion of the treatment of wounds, and particularly of severe wounds, it has constantly to be borne in mind that few surgeons have had the opportunity of dealing with more than one aspect of the problem involved, and consequently any views expressed must to a very large extent be limited to that particular aspect. The passage of a wounded man from the front to a base falls roughly into three stages—namely, the front, the bases in France, and the bases in England, and the treatment and outlook during these three stages are governed by such widely divergent conditions, that any argument from one to the other proves usually to be quite fallacious. It has seemed to us that in very many of the writings on the treatment of war wounds this fact has been, perhaps, partly lost sight of, and we wish particularly to limit our views to those matters of which we have some experience, namely, treatment at the base in France.

There can be no doubt that many of the divergent views which are held, and frequently and forcibly expressed, are due in part to the attempt to argue from facts observed in one place, to a purely imaginary set of conditions in another, and much that is still unsatisfactory in our treatment of the wounded would be helped by a greater fluidity and a freer intellectual communication between surgeons working at the different stages of the wounded man's journey. While evacuation is the key to the successful administrative treatment of the wounded, at the same time it often locks the door to successful surgery and surgical advance, and very often shares in the responsibility for bad results, to a far greater extent than is usually admitted.

Where so many cases have had to be dealt with by surgeons of differing schools, attention has naturally tended to be attracted by detail where principles were really in question, a state of things which has been accentuated by a certain bias taken on by discussions between the protagonists of the chief schools. So much has this been the case, that many articles which have appeared, and which at first sight appear to be entirely opposed to each other, prove, when dissected, to be based on identical lines of thought, which, however, run so tortuously through a mass of detail and test-tubes as to risk being entirely overlooked. In spite of this, however, certain general principles appear to us to be gradually emerging and assuming a definite place in the consideration of a new, and at times a difficult, branch of surgery. It is to these, as they apply to infected wounds of the bones, joints, and muscles at one stage of their course, that we would attempt to confine our remarks.

The trials of a wounded man during the first week of his existence as such are usually very great, including as they do the initial shock and loss of blood, transport from the lines through a field ambulance to the casualty clearing station and thence to the base, and a varying amount of surgical interference and septic infection. The first few days after his arrival, therefore, are largely occupied by sleep, and in removing from his mind and body the unpleasant impressions of life in the front line.

The majority of fractures arrive in splints useful for purposes of transport but not adequate for efficient treatment in hospital. As soon as possible, therefore, the wounded part should be immobilized on a suitable splint, and the patient consequently freed from pain. This, unfortunately, usually necessitates an anæsthetic, in many cases following rather closely on a previous one at the casualty clearing station.

The first function of treatment at a base hospital in France is to limit the spread of infection already present. For this purpose two measures are necessary—namely, adequate rest or immobilization, and the rapid elimination of all dead tissues from the wound. The former is secured by proper splinting, and the latter we have obtained by applying a neutral hypochlorite solution (Dakin and Daufresne) by Carrel's technique. As regards the wound, it is our practice to interfere as little as possible during the first few days. Acute conditions are, of course, dealt with, but as a general rule Carrel tubes are placed in position under the anæsthetic, if one is given, and intermittent irrigation commenced. The less surgery to which a patient is submitted at this stage of his infection, the better his outlook, since Nature's defences are as yet only in process of construction. Pain must be relieved, and it usually is by perfect immobilization; but if for any reason it persists, it must be dealt with by drugs.

It is often contended that the wounded with whom the army has to deal are fit men ordinarily; but it must be remembered that they have undergone a period of stress unheard of in a civilian patient, and consequently their resisting powers are very greatly lowered. The future of a wounded man varies directly with the amount and virulence of his sepsis, and cases which do not have a clean wound after a few days at the base should always be looked upon as serious. The great majority of the cases of compound fracture are infected, some slightly, some intensely, but all to a considerably greater degree than is apparent when they leave the clearing stations, a fact which is a good example of the necessary consequences of evacuation to which we have previously referred.

We propose to discuss the treatment of wounds under two headings: (1) *The part wounded*; (2) *The wound itself*; but it must be remembered that the two lines of thought are completely interdependent, and are in reality necessary corollaries the one to the other. It is, however, in the field of pure wound treatment that the great controversy has raged, where the reactionaries, in the persons of the antiseptic school, and the progressives, or the physiological school, have met in a conflict of opinions and experiments, and where the tactics of detail have tended somewhat to obscure the strategy of principle.

It is, perhaps, a natural attitude that, since the sepsis is caused by organisms, then, when the organisms are once destroyed, all will be well, and an equally natural hope to look to the various antiseptics for such a destructive power. The 'therapeutic co-efficients' and 'bactericidal efficiency' of the laboratory hold out such a dazzling prospect, that when the wound fails to become clean, the tendency is to blame some detail of substance or technique where principles are in reality at fault.

The physiological school, on the other hand, seem to have much weightier arguments on their side; and since their laboratory is that of Nature herself, and their experiments but adaptations of Nature's own, it is possible to feel a certain confidence in the truth of their principles, even if their detail is at times open to question. There can be very little doubt that the treatment of septic wounds which is most likely to promise success is that which most closely imitates Nature's own treatment, or which exaggerates it to meet the aggravated conditions present.

Just what Nature's method is, however, is none too easy a matter to determine, although many competent observers have been engaged in interpreting it. Sir Almroth Wright and his co-workers have carried out a most brilliant and careful research into this subject, and though the methods which they have based upon it have not met with the success which was expected, yet this detracts not at all from the value of their work. Approximately it may be said that, when dealing with an infected wound, the natural reaction of the body is to limit as rapidly as possible the depredations of the invading organisms by destroying the food on which they live, and at the same time to guard against their further invasion by setting up a strong zone of defence around the wound. The first purpose is accomplished by the liberation in the wound, from dead pus cells, of trypsin, which, by splitting up the protein of the dead tissues, deprives the organisms of their pabulum, and forces them to attempt their destructive activities against living, fighting cells. The second is secured by the speedy construction of a band of leucocytic infiltration, and, as a guard against the activity of the body's own agents, by an increase in the normal antitryptic activity of the serum.

We have here, then, the lines on which successful wound treatment can most probably be obtained; and if it be granted that the natural line *is* the most likely to lead to success, it is difficult to find a basis on which the antiseptic school rest their claims, other than the doubtful one of antiquity, or the purely theoretical laboratory qualities with which antiseptics in their modern reincarnation have been endowed.

That the rapid removal of all dead tissue is the best method of dealing with infection is well shown by the success which has attended the early excision of wounds, where, by their nature, complete excision has been possible. This method is, however, only of use in a very early stage, since, when infection is actually in progress, complete removal of all dead tissue and potential dead tissue is not possible.

In the neutral hypochlorite solution of Dakin and Daufresne, we have, however, a substance of very great proteolytic value, and at the same time one which is itself destroyed in the process, a fact which prevents its interfering in any way with the normal action of the tissue cells. Its action on

protein in solution is almost instantaneous, while on coagulated protein its action is many times more rapid than trypsin. It has of course a purely chemical bulk action, and naturally, in a wound where dead tissue is plentiful, must be many times renewed before its action can be completed. This object is achieved by the intermittent irrigation method of Carrel, by which the fluid is brought into contact with all parts of the wound at frequent intervals. It is perhaps unfortunate in a sense that in a test-tube this fluid is possessed of a high 'bactericidal' power. By thus attaining rank as an antiseptic, it has shared any criticisms of these substances, and has had its claims based on a fortuitous property which would appear to us, after considerable experience of its use, to play a quite secondary and relatively unimportant part in its action. The mere fact that within a few seconds after its introduction into a wound, the hypochlorite, as such, ceases to exist, should be sufficient to absolve it from the dubious merit of antiseptic action in a wound; while the fact, which will be discussed while dealing with the bacteriological control, that a smear taken from any isolated portion of dead tissue will still give a high bacterial count when the rest of the wound gives a low one, is further proof of its innocence in this respect.

This all-important proteolytic action of hypochlorite solution, which is responsible for its undoubted efficiency in the treatment of infected wounds, appears to have been very little insisted on, and it is at least interesting to note that Browning and his co-workers refer to it as "the disadvantage possessed by the solution of destroying dead tissues!" Just exactly the nature of the chemical change which occurs in the hypochlorite on contact with protein is obscure, but the proteolytic action undoubtedly goes on to the rapid formation of amino-acids. It would appear probable that along this line—namely, rapid destruction of dead tissues—lies the way to further advance in the treatment of wound infections; and whether future research shows ferment action or chemical hydrolysis to be the more efficient, there can be no doubt that the recognition of the essential nature of this process is of the greatest importance if progress is to be made in dealing with the problems involved.

Nature's second method of dealing with an infected wound—namely, the establishment of a zone of leucocytic defence round the wound—is best aided by the maintenance of absolute rest in the part wounded, and further, by a minimum amount of interference with the wound on the part of the surgeon. Very valuable work has been done by Major Sinclair and others in insisting on the need for effective immobilization in the treatment of infected wounds, and too much stress cannot be laid on the importance of this side of the matter.

Treatment of the Part Wounded.—In wounds of the extremities, whether complicated by fracture or not, it has been our aim to secure immobilization of the limb involved, and at the same time to preserve to the patient as complete a mobility of the rest of the body as possible. This has been secured by carefully splinting the limb, and then suspending the whole splint from overhead pulleys with accurately balanced counter-weights. Any movement of the patient in bed is then followed by the splint, without any disturb-

ance of the injured part, as is shown by the absence of pain. As Hilton points out, "every deviation from this necessary state of rest brings with it, through pain, the admonition that the patient is straying from the condition essential to his restoration;" and with the exception of the presence of pus under tension, pain in wounds is in our experience almost always due to faulty immobilization.

To secure extension, except in certain particular cases to be referred to later, we have used almost entirely Sinclair's glue, which, if carefully applied, is most efficient, and will stand very severe strains if the area of traction is distributed over as wide a surface of skin as possible.

Fig. 349.—Compound fracture of the femur, showing glue extension and suspension.

In any splinting of the lower limb, one of the essential facts to be recognized is that the position of rest and equilibrium in the recumbent position is one of very considerable external rotation, as was pointed out many years ago by Sir Arbuthnot Lane. This fact at once renders unsatisfactory all those splints whose basis is a right-angled vertical foot-piece; a further objection to this form of splint being that it prohibits the normal inverted position of the foot if the splint is to be firmly applied, a point of considerable importance from the point of view of after-results. In dealing with fractures and wounds of the lower limb, we have used almost entirely the Thomas splint, either straight or bent, and suspended in extension on the Hodgen principle; the end of the bed being raised to secure counter-extension.

For fractures of the *Femur*, excepting those very high up, and for extensive thigh wounds, we have used a bent Thomas splint, with a metal archway fixed to the splint in the required position by Mead's strapping, and from which the foot is suspended by gauze glued to the sole of the foot. Extension is obtained by gauze glued to the leg and fixed to the end of the splint, while the whole splint is extended either by a running weight attached to its sides or by a forward position of the suspension pulleys (*Fig.* 349). In the majority of cases good position of the fragments can be fairly readily obtained, since the injury has usually damaged the longitudinal fascial compartments of the limb, and there is not the same incompressible resistance of effused blood, etc., which often renders the non-operative reduction of simple fractures so impossible (Arbuthnot Lane).

FIG. 350.—Compound fracture of the tibia, showing Sinclair's foot-piece in position.

In the matter of compound fractures of the *Tibia*, the ease with which perfect position can be secured varies very greatly with the type of the fracture. The long oblique fracture is always difficult, whereas the transverse or even the intensely comminuted fracture is on the whole readily dealt with. For the latter we have used a Thomas splint, with Sinclair's wooden foot-piece (*Fig.* 350), which consists of a flat piece of wood with serrated edges, so arranged as to be capable of adjustment with regard to the long axis of the leg in every direction. The foot is fixed to this foot-piece by tapes attached to metal triangles threaded on gauze strips glued round the sole. The foot, attached to the foot-piece, is manipulated until the position of the fragments is as perfect as possible, and is then fixed in that position by tightening the fly-nut and attaching the cross-bar to the end of the splint by tapes. By these means the lower fragment is efficiently fixed, and the position of the upper fragment should be maintained by strips of gauze glued to the sides of the leg and attached to the side bars of the splint, thus securing an

absolute immobility of the fragments relative to each other, while the whole leg in the splint can be freely moved.

For the fixation of corrected tibial fractures the foot-piece just described is almost ideal; but although a fair extension can be obtained with it, in our experience the very considerable pull needed to maintain the position of the oblique type of fracture is apt to lead to slipping of the gauze or blistering at the points of attachment of the triangles. For these cases we have used an oblong piece of perforated metal, glued to the sole between layers of flannel, and held in place by cross-bands of gauze running round to the dorsum of the foot. A wire attached to the middle of this piece of metal is fixed to the end of the Thomas splint. This foot-piece will readily sustain a weight of from seven to ten pounds for several weeks.

Fig. 351.—Compound fracture of the metatarsals, extended through the toes.

Fig. 352.—Compound fracture of the humerus, in suspension extension without splints.

At the same time the foot is suspended from an archway by gauze glued to the metal sole-piece.

Fractures of the *Tarsus* and *Metatarsus* have been dealt with by suspension from an archway by the toes (*Fig.* 351), and, if in a Thomas splint, the leg has been kept in position relative to the point of suspension by gauze running from the leg to the bottom of the splint.

Fractures of the *Humerus* we have treated, as a general rule, with the elbow flexed to a right angle, and by methods varying with the position of the fracture and the wounds.

In fractures of and near the head of the humerus, we have found as a rule that a good position is best maintained without a splint, by

merely placing the forearm in a sling, the elbow being fixed to the body by bandages and strapping.

Fractures of the shaft of the humerus, in its middle two-thirds, have been treated in one of two ways, depending on the situation of the wounds. In cases where these are in front or lateral, or in a through-and-through wound, we have used a form of suspension extension without a splint (*Fig.* 352). Glue is applied to the front and back of the forearm, and gauze strips are fixed to it, while, similarly, gauze strips are glued to as great a surface of skin over the lower fragment of the humerus as possible. A mackintosh sling is applied over the dressings round the fracture, and suspended by a cord, which, running over two pulleys, has its other end attached to the gauze glued to the forearm. The necessary weight to secure an accurate counter-balance is attached to the cord between the pulleys. The gauze from the lower end of the arm is fixed to a cord running over a pulley at the end of the bed, to which the required extension weight is attached. By this method free movement of the arm as a whole is permitted without any disturbance of the fracture, and at the same time movements of pronation and supination, and of the fingers, can be freely carried out by the patient from the first.

Fig. 353.—Double compound fracture of the humerus, in bent Thomas splints.

This method is unsuitable for patients with extensive wounds of the back of the arm, or where the extent of the skin involved proves too great for its application. In these cases we have used an arm Thomas splint, bent at a right angle, and with the angles of attachment of the ring altered to fit over the point of the shoulder. When this splint is suspended at the level of the shoulder, the posterior wound becomes external, and is therefore readily accessible for purposes of dressing (see *Fig.* 353, where two of these splints are applied to double compound fractures). Extension is obtained by using the forearm as a lever. Gauze glued to the forearm above the wrist is fixed to the internal bar and forms the fulcrum, while gauze glued to the upper third of the forearm and pulled to the external bar forms the weight, thus exerting traction in the length of the arm. In suspending this splint, the centre point of suspension should be external and in front of its centre, thus preventing any unpleasant pressure of the ring round the shoulder.

Fractures of the *Forearm* have been treated either on this right-angled

Thomas splint, with the upper fragment fixed to the splint and a weight acting on the lower, or by a form of suspension extension tray (*Fig.* 354). This

FIG. 354.—Compound fracture of the radius and ulna, on suspension extension tray.

consists of a metal tray from which a drainage pipe runs, and which has a wooden upright, against which the upper arm rests, to serve as counter-

FIG. 355.—Compound fracture of the carpus, on suspension tray showing finger extension.

extension. The wooden attachment runs forward under the tray, and has at its end a pulley over which runs a cord, taking extension either from the

lower forearm or the fingers, according to the nature of the wound. In certain fractures of both bones a wooden side-piece with straps has been added, so that the forearm can be treated in three-quarter supination. The whole apparatus is counterbalanced in extension, and the drainage tube is connected to a bottle at the side of the bed, thus avoiding any wetting from the solution introduced.

In wounds of the *Carpus* and lower third of the forearm this splint has also been used, usually with a wedge attachment at the end to secure dorsiflexion of the wrist (*Figs.* 355, 361). In these cases extension has been obtained by attaching glued glove-fingers or strapping to the sides of the fingers, and running them by a kind of wood gearing to one central pull. This

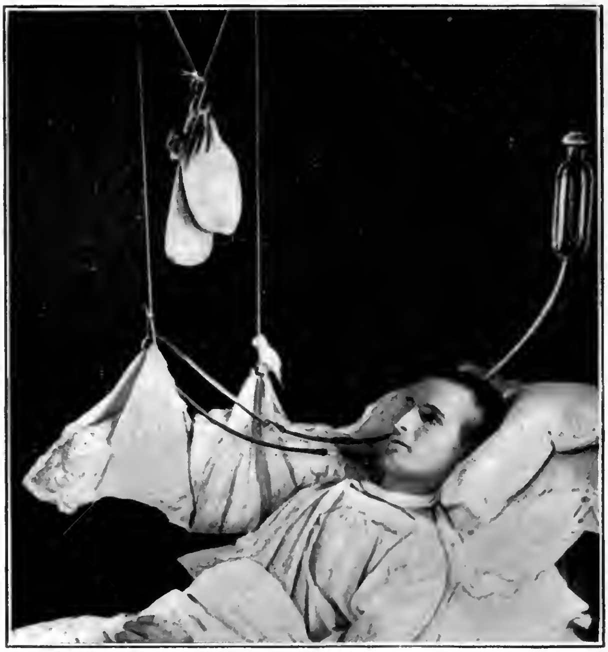

Fig. 356.—Compound fracture of the scapula, showing arm slings.

secures an even distribution of strain, and maintains the fingers in good position (see *Figs.* 355, 361).

In cases of fractured *Scapula* we have found œdema of the arm a troublesome consequence of treatment with the arm at the side, and have been in the habit of suspending the arm at shoulder-level in counterbalanced slings (*Fig.* 356).

In suspending these various splints, we employed at first a form of light scaffolding fitted over each bed (*Fig.* 357), as in use at the American Ambulance at Neuilly; but later we have had fitted inside the hut a permanent superstructure to which cross-bars can be attached in any position, designed for us by Mr. Douglass of this hospital (*Fig.* 358). The advantages of the

FIG. 357.—Ward showing scaffolding over each bed.

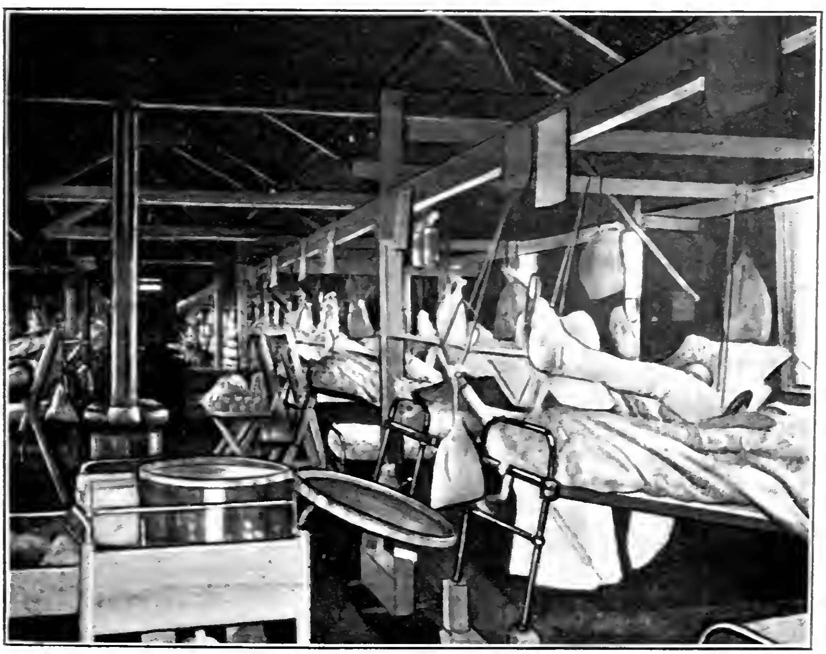

FIG. 358.—Ward with permanent super-structure to which cross-bars can be attached as desired.

suspension splint from the point of view of the patient are obvious, since his range of movement in bed is almost unlimited; while, from the nursing point of view, these otherwise helpless cases can be readily moved and lifted without any fear of injury or pain to the wounded part. That they require a certain amount of care and time in fixing is no doubt true; but the greater comfort, rest, and accessibility obtained adequately compensate for this.

JOINT INJURIES.—In the mechanical treatment of these injuries, the main object has been to arrange the limb in such a position as to obtain as speedy as possible a penetration of the irrigating fluid into all parts of the joint involved. Extension is here the prime need, and where extension is really efficient, immobilization of the injured parts, i.e., the joint surfaces relative to each other, will follow automatically.

In infected wounds of the *Knee-joint*, where a natural arthrotomy was in existence or where a surgical arthrotomy was performed, we have used the metal extension stirrup of Finochietto, which passes over the superior surface of the os calcis close in front of the tendo Achillis, and to which very heavy

FIG. 359.—Compound fracture of the femur with buttock wound, showing Finochietto's extension stirrup applied.

weights can be attached without either pain to the patient or injury to the tissues (*Fig.* 359). The region of entrance and exit of the stirrup is covered with copious sterile gauze bandages, which also serve to maintain the relative position of the stirrup, and to prevent any tendency to calcaneus. We have also used the stirrup in the treatment of certain compound fractures of the femur high up, with very good results. Dr. Chutro and others have used it almost exclusively in the treatment of all fractures of the thigh and leg; but in our opinion the more perfect immobilization of the Thomas splint outweighs the better extension obtained by the stirrup in these cases.

In this matter of securing extension in cases of infected knee-joint wounds, it has been argued that a pull of many pounds can be obtained by gauze glued to the sides of the leg. Our objection to this method is that only a part of such pull is actually felt at the joint, since, owing to the surface of application being the skin, much of it is dissipated by transmission to the skin or fascia of the thigh, i.e., above the joint to be extended.

Elbow-joints have been treated on the suspension extension tray, by which means very good access to both the radio-humeral and humero-ulnar joints is obtained (*Fig.* 360). By this method the joint is flexed to about a right angle, and it has been found that this gives better access to the joint cavity when the irrigation or flushing treatment is being used, than when the elbow is extended.

Wrist-joint wounds, of which we have had several, have been treated in the same way, extension being obtained from the fingers (*Fig.* 361), a wedge attachment being fixed to the tray if dorsiflexion is desired. These cases have been particularly favourable, in spite of the fact of their frequent

Fig. 360.—Wound of the elbow-joint, showing the adaptation thereto of the suspension extension tray.

complication by carpal and metacarpal fractures. Both here and in the ankle there is a tendency to spread of infection along the tendons, and this must be carefully watched for ; it would appear to be due to the fact that dead tendon tissue is not readily hydrolysed, and therefore serves as a nidus for further infection.

Ankle-joints have proved difficult, since they are so frequently complicated by compound fractures of the tarsus ; but in those cases where the skin of the sole is uninjured, a very good separation can be obtained by using the metal sole-piece described above in dealing with oblique fractures of the tibia. A point of great importance in these cases is to obtain a very considerable degree of inversion of the foot, both from the point of view of after-results and of immediate treatment.

We have not had sufficient experience of wounds of the hip and shoulder-

joints to enable us to arrive at any definite conclusions as to their most efficient fixation.

Treatment of the Wound Itself.—Our object here, as pointed out above, has been to destroy as rapidly as possible all dead tissues in the wound. This we have achieved by intermittent irrigation through Carrel's tubes with the hypochlorite solution of Dakin and Daufresne. The general technique of this treatment is now widely known; but as the detail of its application is important, there are some points on which we would lay emphasis.

The first of these is that the desired object of reaching every part of the wound with the fluid can only be obtained by a careful and proper adjustment of the tubes. As a general rule, for the depths of a wound, tubes with a

FIG. 361.—Wound of the wrist-joint, showing gearing extension from the fingers.

few holes are used, since the pressure of flow required is great; while for the surface, where a low pressure is called for, tubes with many holes are employed. Deep and surface tubes should be connected to different supply reservoirs, otherwise the greater proportion of the fluid is necessarily distributed to the surface.

A second point of importance is that the fewest possible number of tubes which will distribute the fluid efficiently should be used. Drainage, which is of equal importance with the irrigation, is then not impeded. It is unfortunately common to see a number of tubes pushed closely together into an opening, thereby acting as an efficient cork, but as little else. Often, again, a tube is seen firmly wedged, or even sewn, into a narrow sinus, where the forcing through of fluid must tend to open up new fascial planes to infection.

Once the tubes have been properly placed, they need not be touched until

they become misplaced or blocked, a matter of time varying up to seven or even ten days.

In dealing with cases of compound fracture, it is advisable, where possible, to verify by a radiogram the fact that the tubes reach to the spaces between the fragments.

It has been the practice here to carry out irrigation with the solution two-hourly. The question of continuous versus intermittent irrigation has been much discussed, and though at first sight the continuous would appear the preferable method, there are many objections to its use. In the first place, from a practical point of view it is almost impossible to ensure the fluid reaching all and every part of the wound by any form of continuous drip, an object which on the other hand is obtained readily by the sudden flush of the intermittent method; this has the additional advantage of sweeping before it the contents of the wound cavity, and thus corresponding to a two-hourly dressing. Again, since the hypochlorite is destroyed within a few seconds after contact with protein in solution, the natural tryptic and phagocytic reactions of the wound are undisturbed, and Nature is enabled to lend her valuable help in cleaning the wound in the interval between the flushings. In the early stages of an infected wound where dead tissue is plentiful, hourly irrigation is preferable.

There is no danger of burning or irritation of the surrounding tissues so long as there is pus in the wound. When, however, sterility approaches, and dead tissues disappear from the wound, the surrounding skin must be carefully vaselined to protect it from the action of the hypochlorite.

To minimize as far as possible the disturbance of dressings, we have avoided the use of wool and bandages, and have used instead large pads made of layers of wool between gauze, and specially shaped and sewn to fit the different anatomical regions. These soak up the discharge and overflow of fluid to a certain extent; the remainder runs into large metal trays placed under the limb or body, and drains into a bottle beside the bed. These large dressings must be changed at first perhaps every other day; but as the wound cleans, it is possible to leave them up to a week or more, a matter of great importance when the disturbance of holding and bandaging a fractured limb is remembered. As a routine, the wounds are dressed every other day: but this dressing is merely a matter of changing the gauze and seeing that the tubes are pervious and in position. In painful cases, such as guillotine amputations, the dressings may be left untouched in perfect safety for a week or ten days, a great comfort to the patient.

SURGICAL TREATMENT.

In addition to the lines of treatment sketched above, ordinary surgical principles as they apply to infected wounds must be observed; but it has appeared that certain modifications of some of the usual procedures are desirable.

The provision of efficient drainage is of course as essential under these conditions as under any others, and a complete opening up of the original wound, and well-placed counter-incisions, are all important, particularly in

the case of compound fractures. All pockets and portions of the wound must be made freely accessible to the irrigating fluid, since an area of dead tissue in some recess where it is not reached and therefore not dissolved by the hypochlorite will, at the least, continuously reinfect the wound. As far as possible use is made of anterior incisions, to facilitate both dressing and splinting, but in almost all compound fractures—of the femur, at any rate—a free approach from two directions is necessary.

In the early stages of acute sepsis we would advocate the least possible manipulation of limbs in search of hidden or pocketed pus, as in the majority of cases, if the immobilization is good, a barrier will be formed against any general spread of infection, and pus, if it is formed, will be local in site and readily dealt with when the moment arrives. The early exploration of such doubtful wounds with instruments or fingers would seem to serve no useful purpose; and always provided that incisions and counter-incisions are well placed and free, and splinting sound, it would seem both safe and desirable to wait for the pus, if present, to announce its formation as a fluctuating abscess, or by a leak into the general cavity of the wound. Any spreading cellulitis or an acute abscess must of course be dealt with, preferably in bed, under gas, to ensure a minimum of movement to the affected part.

As a general rule cases have been kept at this hospital until they have advanced to a stage where any serious complication is unlikely, but in very few instances until they have run their full course. Since the efficiency or otherwise of any early surgical treatment can only ultimately be judged by end-results, any expressions of opinion as to such treatment must be tentative, and subject to correction where results prove bad.

Fractures.—Immobilization has already been discussed; in addition, as perfect as possible a position of fragments must be obtained, and obtained early. There can be no doubt that the better the alinement of the limb—by which is meant the position not only of the bone fragments, but of muscles, nerves, vessels, and lymphatics as well—the more rapid will be the diminution of pain and sepsis. Major Sinclair has most ably demonstrated the importance of this principle, and we wish to acknowledge our indebtedness to him for many ideas and suggestions.

In dealing with a large number of compound gunshot fractures, the problem of what to do with loose or partially loose fragments of bone assumes an even larger aspect than in civil practice, and considerable divergence of opinion exists as to the best line to be adopted. There is no doubt that by removing all loose pieces, a more rapid sterilization, and possibly a quicker closure of the wound, can be obtained. Those who favour this plan have as their object the conversion of a compound into a simple fracture as soon as possible with a minimum of sepsis, and hold that any loss of substance needing repair can be dealt with later. A certain confidence which the above described line of treatment has given us in its ability to control the spread of infection in compound fractures, has induced us to lean towards the opposite extreme. Completely detached fragments are of course removed, but any piece bearing any attachment to the tissues has been left, and it has often been found that such pieces become firmly attached later, and play a most important part in

the deposit of callus along the line of the bone. Occasionally removal of a piece of bone may be necessary to obtain more efficient drainage, but this should be avoided whenever it possibly can. There can be no doubt that by this attitude the probabilities of obtaining a better bone anatomically are greater. In the lower limb, where function and structure go hand in hand, this is perhaps more important than in the upper limb, where a rapid control of sepsis and a speedy resumption of movement are all-important.

The question of completely closing a wound in cases of compound fracture is very open to debate. Though there can be no doubt that where it is successful it prevents to a very great extent troublesome adhesions between bones, muscles, and skin; yet, excepting in certain very simple cases, the bacteriological control of the bony interspaces must always be, at the best, uncertain, and the procedure, therefore, always risky. The gain of closure in such cases has not seemed sufficient, except in a few instances, to counter-balance the risk; and, in addition, the moment for evacuation has usually arrived when the question of suture comes under serious consideration.

Wounds of Joints.—Much attention has been paid during the war to the treatment of infected joint wounds, and although certain methods have been advocated for a time and have then been dropped, yet on the whole very considerable advance has been made, and many limbs can now be saved which would have been lost in the past. Very many wounds of joints, more particularly perhaps those of the knee-joint, that have been washed out and closed as a primary measure at the casualty clearing station, have reached this hospital; and while in some cases suppurative arthritis has intervened, up to two weeks or more after closure, the results have been remarkably good on the whole. In contrast to what is the case in compound fractures, everything is to be gained by such an early closure of joint wounds, while if they are carefully watched, the danger to the patient is not greatly increased by this procedure. In successful cases an almost perfect joint rapidly results; while in cases that fail, the failure is not greatly aggravated by the attempt at perfection. Where suppurative arthritis does occur, the problems to be faced are mainly concerned with the mode of access to the joint and the method of extension, the latter of which has been discussed above. The question of access must be considered in connection with the particular treatment of the joint cavity used; it differs somewhat where irrigation by the proteolytic hypochlorite solution is employed, from that suitable where simple drainage alone is relied on, since in the former the flush of irrigation negatives the stagnation effect of gravity which must be dealt with in the latter.

In the case of the *Knee-joint*, both treatment and prognosis seem to depend upon whether the infection is limited to the part of the cavity anterior to the crucial ligaments, or whether the posterior portion of the joint is involved as well; and there can be no doubt that the outlook in the latter case for both limb and life is much more serious.

The first essential in the treatment of all these cases is extension, and the earlier this can be applied the more hopeful the result. Such an extension

must be of sufficient force to ensure an actual stretching of the ligaments, and thereby a separation of the joint surfaces. We have secured this pull by the use of the stirrup described above, which seems to have a very definite value in the treatment of these cases.

In early infections repeated aspirations may be tried, but should not be persisted in in the face of an unfavourable bacteriological report. The importance of such an examination, both as regards immediate treatment and ultimate result, has been rightly insisted on by Lazarus Barlow in a very instructive article.

When arthrotomy is decided upon, it must, to be effective, give free access and enable the irrigating fluid to reach all parts of the joint involved. Incisions on either side of the ligamentum patellæ enable the anterior part of the main joint, and the articulation between the patella and the femur, to be reached, while in addition a small incision at the topmost part of the suprapatellar pouch is usually necessary to control this cavity efficiently. In cases which run a favourable course, the irrigation tubes can be withdrawn to the level of the capsule after a few days, and movement, as far as is allowed by the extension, can be encouraged (a great advantage of the stirrup). If the infection does not tend to come under control, the possibility of a post-crucial spread must be borne in mind, but any early extensive posterior incisions are to be deprecated. If sufficient extension is maintained, it is usually safe to allow pus to point behind before interfering. By this attitude the dangers of opening new paths to infection are lessened, and much anatomical disturbance avoided, while the possibility of the infection being in reality still ante-crucial is given every opportunity of declaring itself.

In the *Elbow-joint* the case is rather different, in that the majority of wounds of this joint are complications of fractures of the bones entering into its formation, and therefore the early treatment by washing out and suture is seldom possible. In many cases the incisions for drainage of the fracture can be made to serve the same purpose for the joint, but in others separate incisions are needed, and here again the provision of access to all parts of the joint is the main essential. In these cases, and in those in which a deliberate arthrotomy is required for a suppurative arthritis complicating fractures round the joint, we have used a longitudinal incision over the head of the radius in preference to the more usual posterior incision, and have treated the joint in flexion rather than in extension. This incision not only gives very good access to the elbow-joint proper, but in addition brings the orbicular ligament under the eye of the surgeon, and allows early interference in case of infection before the all-important radio-ulnar joint becomes disorganized. This incision is of course only efficient in the flexed position of the limb; and since in this position it is anterior, it presents also the advantages of allowing adequate flushing with the hypochlorite solution and ready accessibility for dressing purposes. With this method, results on the whole have been remarkably good; and although in many cases no doubt arthroplasty or excision may ultimately be needed to secure mobility, the control of the sepsis has not called for it in any of our cases.

Excision has had its claims urged by several surgeons as a primary method in dealing with infected elbow-joints; but it is difficult to see what

advantage this operation has to offer, when the fact that infection can almost always be controlled without it is balanced against the very definite and serious drawbacks of the method when used during the stage of acute infection. The whole question of excision of joints is shrouded in considerable mystery, owing to the differing conditions of the wounds and of the objects sought by the operations. With excisions performed for orthopædic purposes we have no concern, since this is a matter entirely beyond the sphere of base hospital work in France; but many surgeons both in France and in England advocate excision for purely drainage purposes, or, in other words, as a conservative operation, both in elbow and knee-joint injuries of a severe type. While admittedly these cases are some of the most difficult to control of any infected wounds, it would seem doubtful whether excision, at any rate in the knee and elbow, has any advantages to offer. If really efficient drainage is to be secured, a very considerable margin of bone must be sacrificed, a fact which, in the knee more particularly, makes the end-results of these cases problematical in the extreme. In addition, the whole zone of defence of the patient is disturbed, and an organism already at the extreme limit of resistance is suddenly brought face to face with an entirely fresh bacterial attack which it is quite unprepared to meet. A further disadvantage of excision must always be that the margin in these cases is small, and that should improvement not occur very quickly after this operation, amputation will be called for, and the patient be forced to submit to two extensive surgical measures within a very short space of time.

On the one hand, then, we have the less active treatment, of simple drainage and hypochlorite irrigation, with, as its best result, a useful limb, and, as its worst, amputation when the margin of safe delay is exhausted. On the other hand we have excision, with, as its best result, a limb the usefulness of which—bearing in mind the free removal of bone and the prolonged drainage—is problematical, and, as its worst result, amputation in the face of a margin of safety gravely curtailed by a previous extensive operation. In the case of the elbow-joint in particular, the great readiness with which these cases have come under control has given us no need to take the question of excision into serious consideration, at any rate as a means of controlling infection.

Secondary Amputation.—This is probably one of the questions needing a better judgement and more careful weighing of pros and cons than any other which a surgeon at a base hospital in France has to deal with. That in each case there is a certain margin of safety, which dare not be overstepped, in attempting to continue conservative treatment, is undoubted, and the recognition of the moment when this limit is reached is often fraught with great difficulty. It is just one of those points which must be considered entirely afresh in each individual case, and a series of successfully conserved cases on the one hand, or of failures on the other, must not be allowed to weigh unduly in deciding on the treatment of any particular individual. The problem consists in balancing the chance of losing or shortening lives by prolonged attempts to save limbs, against that of sacrificing limbs which might have been saved in the end. Now, while the instrument makers have no doubt

advanced greatly in the design and construction of artificial limbs, yet at the best such a limb is a poor thing, putting the patient at a disadvantage in his struggle for existence, a fact which is often not sufficiently recognized when the question of amputation is being considered. Some of the most unsatisfactory results of conservative treatment, provided they are painless, are often better than the best artificial limb; and while this is true of the lower limb, it is doubly so of the upper. Another fact to be borne in mind is that the scope of orthopædic surgery to-day is such that, until it has had its chance, it is practically impossible to condemn any limb as useless.

Bearing these points in mind, we have on the whole tended towards extreme conservatism; and although in one case death may have been due to this attitude, there are many others in which quite sound limbs have been saved which at one stage appeared unsaveable. In a large series of compound fractures we have performed 12 amputations, of which 8 were for shell wounds of the tarsus and ankle-joint (one being for acute infective gangrene); in these cases the fact that has helped to influence us in not continuing conservative treatment unduly is the very dubious end-results which could be obtained in these severe tarsal fractures; and it has been held better to seize the moment when a low amputation is safe, rather than run the chance of losing considerable length of limb in trying to save a foot of very doubtful value. Of the remaining four, two were suppurating knee-joint wounds, in one of which death resulted (the case referred to above). A third was an arm with a disorganized elbow-joint and a wound of the forearm destroying the ulnar nerve; this was amputated on the occasion of the third secondary hæmorrhage. The fourth case was of a different type, being an amputation through the thigh for spreading gangrene following a traumatic aneurysm of the posterior tibial artery; in this case death followed from acute toxæmia.*

Wounds of Muscles, uncomplicated by bony injury, are much less difficult to deal with; but by their frequency, and the disability which may result from adhesions or massive scar-formation, they require careful handling. Rest is just as essential a part of the treatment of these wounds as of that of compound fractures, and this is particularly the case where tendon sheaths are laid open to the spread of infection. By the use of hypochlorite, such sloughing and suppurating muscle wounds can be freed of all dead tissue in a period of a few days; with the possible exception that dead tendon tissue, being difficult of hydrolysis, needs removal with the scissors. All these wounds can be wholly or partially closed when sterilized; and there can be little doubt that the more extensive use of this procedure, under the effective control of bacteriological examination, would ensure the avoidance of much disability and many painful or contracted scars. In deep or through-and-through wounds of a muscular part such as the thigh, it occasionally happens that suppuration and a high bacterial count persist beyond the usual time. In these cases, if no foreign body is present, it will almost invariably be found on exploring the wound that a portion of dead tendon tissue, consisting of

* This case was not one of compound fracture. It is included here for the sake of completeness, but will not be found in the appendix of cases.

an aponeurosis or tendinous intersection, has resisted solution and acted as a base for continued bacterial attack. If such portions are removed, the wound will be found to come quickly under control.

There is a certain type of patient suffering from multiple muscle wounds, none of them necessarily severe, in whom a curious lack of reaction shows itself. He appears to have lost all power of response to infection: he does not produce pus, nor is there any evidence of the formation of a reacting inflammatory zone. Such a patient tends to go down hill steadily, and die. These cases present a pathological problem of great interest, in that it is difficult to understand why 'shock' should interfere with what must be entirely a chemical reaction; and again, if 'shock' *is* responsible, it is not clear why it should be so severe in a patient whose total wound area may be considerably less than that of a vigorously reacting single-wound case.

COMPLICATIONS.

The prognosis of any severely infected wound can seldom be predicted with any certainty when it is first seen, depending as it does on so many factors, such as the resistance and reacting powers of the patient, of which we have at present no scientific measure.

One of the most fatal complications which can occur in the course of an infected wound is a *septicæmia*, and there would appear to be no indication either in the site or nature of the wound, or in that of the infection, from which warning of its onset can be obtained. Just what the conditions are which are capable of upsetting the balance between the defences of the body and the attacking organisms, so as to enable the latter to obtain undisputed access into the general circulation, is not very clear, but there are certain factors which undoubtedly tend to help such an occurrence. One of the most important of these, under certain conditions, is undoubtedly inefficient drainage. Although this may lead to spreading cellulitis and abscess formation in a limb under any conditions, it would appear that where rest is absolute, the body can usually prevent any complete breaking through of its defences; but where faulty immobilization, especially when subject to the stress of transport, is added to inefficient drainage, the dangers of a septicæmia would appear to be considerable. This is one of the great disadvantages to be urged against the complete early closure of wounds, either complicated with fractures or without, under circumstances where early and frequent transport is a necessity of the patient's future, when no absolute certainty can be felt that infection is completely mastered. The same risk attends any extensive surgical interference during the stages of acute infection: and since with rigid immobilization the occurrence of a general infection is almost unknown, it is a great deal safer to wait until fluctuating pus calls for a purely local intervention, than to make extensive incisions on the ground of local inflammatory signs, with the risk of a fatal septicæmia to follow.

In addition to septicæmia, another severe and at times dangerous complication of infected wounds has to be feared, namely, *secondary hæmorrhage*. At first sight, since the avowed object of using hypochlorite in the treatment

of infected wounds is the rapid solution of dead protein, it would seem probable that secondary hæmorrhage should be commoner with this treatment than with others, since blood-clot is very readily dissolved by the fluid. But in a large number of cases so treated there has been no undue frequency of this complication, though it has occurred in a certain number: it seems probable, however, that in the latter the secondary hæmorrhage was in no way due to the hypochlorite, since when it did occur it was in wounds intensely septic, where pus—that is, protein in solution—was plentiful, and in such wounds the hypochlorite as such is destroyed within a few seconds after its introduction, long before it could have any action on the blood-clot. It has, however, been our practice to pay particular attention to bleeding points after any operative measure where bleeding occurs, and, in addition, not to introduce the hypochlorite solution for at least twelve hours after operation, so as to diminish the chances of oozing.

The fact that secondary hæmorrhage, as such, occurs almost invariably in extremely septic wounds, and especially where the sepsis is tending to spread, leads one to believe that inefficient drainage is mainly concerned in its causation, though the intense general prostration in proportion to the amount of blood actually lost points rather to a more obscure origin.

MODE OF ACTION OF HYPOCHLORITE SOLUTION.

At the present moment there is still considerable uncertainty both as to the mode of action of the hypochlorite solution and the exact nature of its break-down products. Further, very different results have been obtained by different observers as to its direct 'bactericidal value,' especially in the presence of pus or serum. Our own view is that as a pure bactericidal agent—in the sense of *directly* destroying micro-organisms—its action is unimportant, and that its undoubted value in the treatment of infected wounds depends on its power of destroying dead tissue, and so depriving the infecting organisms of their pabulum.

Experiments made to determine the action of a 0·5 per cent hypochlorite solution on coagulated albumin, gelatin, albumin in solution, and dead tissue, showed that the solid protein was dissolved, and the protein in solution altered. This alteration consists in an hydrolysis of the protein, which appears to be complete, and the various stages of the formation of alkali albumin, proteoses, peptone, and lower products can be followed. The action is a bulk action, and since the hypochlorite is itself decomposed in the process, the amount to be used bears a direct ratio to the amount of protein to be destroyed; this fact explains the apparent failure of Dakin's solution in Sir Almroth Wright's 'artificial slough' experiments. As an example: In a solution containing 5 per cent egg-white and 0·5 per cent hypochlorite, no protein, proteoses, or peptone could be detected after eight hours' incubation, although all these substances could be found at varying stages in the experiment.

Muscle, catgut, silk, and cotton were all destroyed readily *in vitro*. This is not the case, however, with bone. If a weighed piece of bone with soft tissues attached is submitted to the action of hypochlorite solution, there is at first a slight gain in weight, after which the weight steadily diminishes until

the soft tissue is completely dissolved, when the weight remains constant under further treatment. Although the ready solution of ligature material would appear at first sight to present a danger in the use of hypochlorite in wounds, this is not so in practice, since the amount of protein in solution present in a wound is sufficient to neutralize the hypochlorite as introduced. This fact also accounts for the absence of any injury to the living tissues when the hypochlorite is introduced under these conditions, a fact well shown by the normal appearance and phagocytic activity of the white cells as seen in the smears examined from the wounds under treatment.

In direct proportion as the dead tissue disappears, the organisms, as shown by the bacterial controls, diminish in number, since most organisms need at any rate polypeptides for their growth, and these are hydrolysed into simpler products by the hypochlorite. Wright points out that the streptococci and the staphylococci are the only organisms able to assimilate the protein in serum, which he speaks of as being 'protected' from digestion by the anti-trypsin of that fluid. In this connection it is interesting to note that a study of the nature of the flora of wounds treated here by hypochlorite shows that the coliform and sporing bacilli disappear first, then *B. Welchii*, and that the streptococci and staphylococci are the most persistent. An exception, however, is *B. pyocyaneus*, which has sometimes made its first appearance when the wound was relatively free from other organisms and was clean, and the suggestion is made that this organism may be able to develop in the absence of peptone or polypeptides.

BACTERIOLOGICAL CONTROL.

Films from the most infected part of each wound have been prepared and examined every other day by the method worked out at Dr. Carrel's hospital, and the number of organisms per field of the microscope is entered on a chart (*Fig.* 362), and forms an efficient guide to the progress of the wound. At the same time, in examining these films, the type of organism is also noted, as well as the nature of the cells, particularly the relative number of mononuclears, and their condition of preservation, phagocytic activity, etc. While such a control can by its nature only be approximate, it is found in practice to be most efficient, both in relation to the progress of the wound, and to the moment for suture, if that is aimed at. If the hypochlorite is reaching all parts of the wound, and in consequence dead tissue is being evenly eliminated, the chart will be found to have a steady downward tendency. The persistence of a high bacterial count, provided there is no fault of technique, almost always points to the presence of a foreign body of some kind, or to the fact that all parts of the wound are not being reached by the solution.

In the course of the routine examinations here, the tetanus bacillus has been found in a certain number of cases, and although in none of these has tetanus developed, yet the recognition of this organism is an indication for active prophylaxis.

As regards the cell content of the films, at first only polymorphonuclears are seen; but as 'sterilization' proceeds, the large lymphocytes and endothelial cells come into evidence, until they may number one to every six or

seven polymorphonuclears. A large percentage of mononuclears, however, is sometimes seen when there are still many organisms, and vice versa; but in general it may be said that the appearance of mononuclear cells is a favourable indication.

On the lines described above we have attempted to carry out a system of treatment based on the principle of assisting Nature in the process of repair; and it is because we have been fortunate in having a number of severely infected cases to deal with under conditions allowing of observation in some detail,

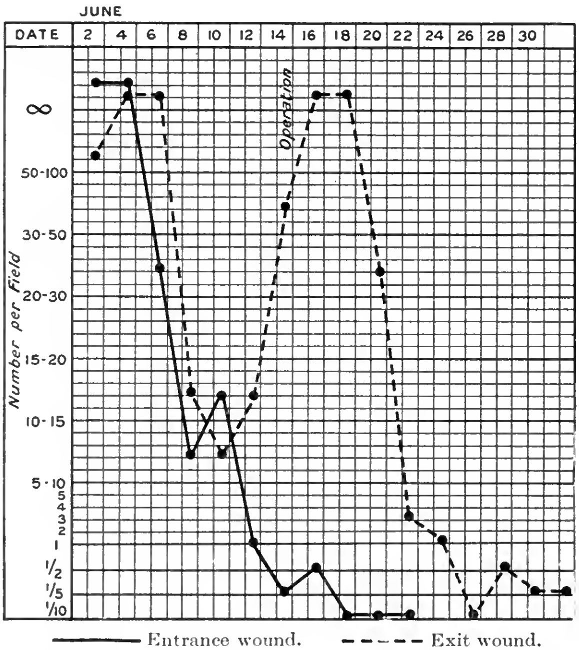

FIG. 362.– Bacterial chart from a case of through-and-through wound of the thigh. A piece of clothing was removed from the exit wound on June 14.

that we bring forward these notes. The gradual recognition of the importance of contamination and reinfection of infected wounds has led to the development of aseptic principles as applied to their treatment; and it seems that much the same evolution of thought is taking place to-day in regard to infected war wounds, as took place in the past in regard to general operative surgery.

A proper insistence on the essential importance of such aseptic principles we owe to Dr. Alexis Carrel, as well as the technique of the irrigation method bearing his name which has proved so valuable in the treatment of war wounds. Although in many ways unable to agree with his interpretation of the mode of action of hypochlorite solution, we wish to express our gratitude to him for his great courtesy and help during a visit to his hospital at Compiègne, and our admiration of the valuable work carried out there by himself and his co-workers.

Much of the work recorded in this paper could not have been carried out without the help and co-operation of Dr. C. Dean, who has been responsible for the medical and bacteriological work at this hospital. He has employed the principles discussed in this paper in a large number of chest wounds, and the results which he has obtained are appearing in the *Quarterly Journal of Medicine.*

We further wish to express our thanks to Millicent, Duchess of Sutherland, for the enthusiastic and understanding manner in which she has helped us to carry out this treatment, and to the nursing staff of this hospital, whose interest and co-operation in the work have been invaluable. Mr. H. A. Douglass, A.R.I.B.A., we have to thank for his able assistance in the design and construction of splints, Miss E. McNeill for her careful compilation of records, and Private J. Gowans, R.A.M.C., for much valuable help in the laboratory work.

It has seemed to us desirable in the following Appendix, which gives an abstract of a certain number of cases treated on the above lines, only to record such as have been kept under treatment here until all reasonable probability of the usual complications occurring has passed. While by such a selection, naturally, all the failures are presented, yet it seems to us more satisfactory than to publish a larger number of cases the ultimate outcome of which is unknown, in order to show more favourable statistics. The appended cases (pp. 449–461) are brought up to date to August 15, 1917.

APPENDIX.

A. SUMMARY OF MUSCLE WOUNDS:

A Statistical Summary of 48 Cases, selected chiefly for their large surface area, or involvement of important muscles.

13 cases had an initial infinity count, the rest being of varying lower septicity.
Average time to disappearance of visible dead tissue, was just over 9 days.
7 of the 48 cases were still incompletely sterile on transfer.
10 cases were sutured with perfect success.
4 cases were sutured with partial success.
In 2 of the partial failures the skin could not be approximated.
27 cases were sterile on transfer.

B.—TABLE OF CASES.

T. No.	Days after wound when admitted	G = Gunshot wound S = Shell wound	Temperature °F	Sepsis: No. of bacteria per microscopic field	Wound, Complications, etc.	Disappearance of visible dead tissue, in days	Days taken to obtain sterility	Days under treatment	Condition on transfer
2502	4	G	100	2	Compound fracture of *femur*. Foreign body removed here. Wound sterilized and sewn up. Bone plated 28th day after suture	7	20	71	Primary union
2451	12	G	102	15–20	Compound comminuted fracture of *femur* . .	20	38	48	Union. No sinus
2450	12	S	100	5	Compound fracture of external condyle of *femur*	18	26	35	Wound healthy. No sinus
2440	7	S	101	∞	Transverse fracture of *femur* just below trochanter	10	14	63	No sinus to bone
2412	5	G	101	50–100	Compound comminuted fracture of lower third of *femur*. Secondary abscess	13	Incomplete	71	Sinus to ? sequestrum
OT44	9	S	102	5–10	Compound comminuted fracture of lower third of *femur*	19	Incomplete	51	No sinus. No sequestra
2983	7	S	99·5	∞	Large wound. Compound fracture of internal condyle of *femur*	9	15	18	Superficial granulating surface
2902	7	S	101	20–30	Perforating wound. Oblique fracture of *femur*	9	11	34	Small sinus present, which has been sterile for 20 days
2741	7	S	100	50–100	Large anterior wound of thigh. Much laceration of muscles. Comminution of middle third of shaft of *femur*	30	49	69	Definite union. Sinus still present
2833	11	S	101	∞	Perforating wound of lower third of thigh. Comminution of *femur*	21	30	52	Wounds clean. Small sinus
3133	3	S	103	∞	Lacerating wound, exposing about five inches of comminuted *femur*	25	Incomplete	—	Still under treatment
[illegible]	[illegible]	S	101	∞	Compound fracture of *femur*	25	Incomplete	—	Still under treatment

2761	3	G	101·5	—	Small anterior, large posterior wounds. Compound fracture of middle third of *femur*	28	—	60	Wounds superficial. No sinus
2890	5	G	101	2	Perforating wound of middle third of right thigh, large external opening. Long oblique fracture of *femur*	9	13	54	External wound sewn up 38th day, partial success
3125	12	S	100	∞	Compound fracture of lower end of *femur*, implicating *knee-joint*	15	24	—	Still under treatment
2822	3	G	101	∞	Perforating wound of left thigh, involving *suprapatellar pouch*	13	19	43	Wounds superficial
2498	7	G	100	30–50	Through-and-through wound on posterior aspect of *knee-joint*	4	11	22	Primary union after suture
2447	12	G	101·8	30–50	*Patella* exposed. Laceration of extensor muscles. *Joint* exposed. Counter-incisions into main joint-cavity and suprapatellar pouch	38	50	80	Small sinus. Wounds healthy
2634	2	S	101·2	½	Compound comminuted fracture of *patella* ..	7	17	19	Wound almost closed. Anterior joint-cavity alone involved
2450	12	G	100	5	Penetrating wound of *knee-joint* with fracture of external condyle of *femur*	18	Incomplete	25	Sinus still present. Wound healthy
2627	9	G	101·4	2	Large wound of popliteal space, involving *knee-joint*	2	12	20	Wound sutured. Primary union
2585	8	S	101·4	5	Compound comminuted fracture of *patella* ..	9	12	17	No sinus. Wound superficial and clean. Anterior joint-cavity alone involved
2865	2	S	100·2	∞	Wound of *suprapatellar pouch*	16	21	25	Wound quite clean
2780	5	G	103	15–20	Wound of *knee-joint* partially sutured at C.C.S. Pus evacuated from anterior part of joint here	30	60	90	Knee still swollen. No discharging sinuses
2912	9	S	102	∞	Wound of right *knee-joint*. Joint opened, patella wired, and joint closed at C.C.S. Re-opened for acute sepsis on admission here	60	75	77	Wounds clean. No sinus

Continued on next page.

TABLE OF CASES—*continued.*

T. No.	Days after wound when admitted	G = Gunshot wound S = Shell wound	Temperature °F	Sepsis: No. of bacteria per microscopic field	Wound, Complications, etc.	Disappearance of visible dead tissue, in days	Days taken to obtain sterility	Days under treatment	Condition on transfer
2757	4	G	101	∞	Tunnel track through upper end of *tibia*, involving *knee-joint*	17	22	100	Wounds completely healed over
OT49	14	S	102	20–30	Wound of left *knee-joint*, sewn up at C.C.S. Re-opened for pus here. Compound fracture of head of *tibia* found at operation. Several times during convalescence it was thought leg would have to be amputated	45	58	79	Wounds superficial. No sinus
2829	4	S	102	15–20	Left *knee-joint* washed out and closed at C.C.S. Stitches removed here, with escape of large quantity of pus	16	23	74	Wounds superficial and granulating. No sinus
2877	23	S	—	20–30	Wound of right *knee-joint*, closed at C.C.S. Considerable œdema on admission here. Joint re-opened. Quantity of pus evacuated	15	22	60	Wound superficial. One shallow sinus
2549	5	G	103	∞	Perforating wound, with fracture of upper end of *tibia* into *knee-joint*. Multiple other wounds. Secondary hæmorrhage of right arm, which made patient so ill that amputation of leg became necessary. Blood transfusion at operation	—	—	—	Amputation 1 month 26 days after admission. Died 12 days later
2851	5	S	100	∞	Compound fracture of head of *tibia* involving *knee-joint*. Post-crucial infection	—	—	32	General condition grave and getting worse. Amputation lower third of thigh. Recovery
2534	3	S	100·8	∞	Compound comminuted fracture of *tibia* and *fibula*. Gap of 2 in. in tibia. Much destruction of muscle	30	49	58	Wound clean. Shallow sinus still present
2851	2	S	99·8	Slight	Perforation of *tibia* with [illegible]	2	Incomplete	5	Wound [illegible]

					middle third of *tibia*				to site of fracture. Wound healthy on admission
2547	14	S	100·8	20–30	Compound comminuted fracture of lower third of *tibia*	10	18	30	Wound clean. Sinus to bone
2525	6	G	99	5–10	Bullet has splintered *tibia*, but there is no actual discontinuity	5	8	21	Wound sterile. Small sinus to cavity
2467	6	S	102·6	∞	Compound oblique fracture of *tibia*	20	46	60	Union. Wound nearly closed. No sinus
2443	5	S	100·8	∞	Compound comminuted fracture of lower third of *tibia*. Bone exposed in wound. Sequestra removed	20	50	63	Wounds clean. Some union. Sinus to fracture
2785	2	S	102·4	50–100	Incomplete fracture of *tibia*. Much comminution, but medial border not destroyed	10	Incomplete	41	Surface wounds clean and granulating. Sinus still present
2975	4	S	102·2	∞	Compound comminuted fracture of lower end of *tibia*, very oblique. After 60 days wound clean and sterile. Position bad. Six-holed plate applied. Wound left open. Carrel tubes inserted. Bacterial curve went up to 30–50. Sterile again in 18 days	30	50	—	Still under treatment. Plate covered. No sinus. Plate removed later, wound healed
3052	5	S	—		Oblique fracture of *tibia*	11	20	—	Union. No sinus. Wound still under treatment
2967	3	S	101	20–30	Compound comminuted fracture of *tibia*. Perforating wound	13	50	—	Wound sterile. Firm union
2906	3	S	100	∞	Perforating wound of lower part of leg. Compound fracture of *tibia*. Secondary hæmorrhage from posterior tibial artery 7th day after admission. Sequestra removed on 34th day	40	Incomplete	56	—
2977	4	S	104	5–10	Perforating wound. Badly comminuted fracture of middle of *tibia*	10	15	47	Union commencing. Wounds clean

Continued on next page.

TABLE OF CASES—*continued.*

T. No.	Days after wound when admitted	G = Gunshot wound S = Shell wound	Temperature °F	Sepsis: No. of bacteria per microscopic field	Wound, Complications, etc.	Disappearance of visible dead tissue, in days	Days taken to obtain sterility	Days under treatment	Condition on transfer
2791	3	S	103	∞	Comminution of *tibia* and *fibula* 2 in. above ankle-joint. Much loss of substance	30	Incomplete	52	Alinement good. Large gap still present. Numerous sequestra continually coming away
2827	2	S	101	20–30	Excavation of head of *tibia*	30	46	102	Wound clean and superficial. No sinus
3037	5	S	—	∞	Compound comminuted fracture of middle third of *tibia*	14	18	33	Wounds clean
2866	4	S	102	∞	Large lacerated wound of lower third of leg. Compound fracture of *tibia*	43	Incomplete	72	No union. Several sequestra still present
2868	5	S	102	∞	Compound fracture of middle third of *tibia*. Lacerated wound on anterior aspect of leg. Several secondary abscesses	60	Incomplete	72	Some union. Sequestra still present
2757	4	G	101	20–30	Tunnel track through upper end of *tibia*, implicating *knee-joint*	60	75	100	Wound closing
OT73	1	G	102	∞	Perforating wound. Compound fracture of *tibia* and *fibula*	14	30	44	Union. Small sinus
OT56	2	S	100	∞	Large, intensely foul wound on anterior aspect of leg. Large excavation in head of *tibia*. Tetanus bacilli present	45	Incomplete	87	Excavation filled with granulation tissue. Wound closing
2950	3	S	102	∞	Wound on outer side of leg. Foreign body removed from head of *tibia*	8	13	30	Wound superficial. No sinus
2776	2	S	101	∞	Extensive wound on inner aspect of leg. Much destruction of middle third of *tibia*	20	38	70	Wound clean & closing. Sinus present. Infection by *B. pyocyaneus* delayed sterilization

2606	6	G	99·6	5–10	Large wound of outer side of leg. Compound fracture of *fibula*. Much loss of substance	12	30	65	Wound sterile and closing rapidly. No sinus
2688	12	G	99·4	∞	Multiple wounds of outer side of leg. Compound fracture of *fibula*	23	34	56	Wounds sterile and closing rapidly. No sinus
2963	4	S	99	—	Compound fracture of lower end of *fibula* ..	5	8	12	Wounds superficial
3015	3	S	100	∞	Compound comminuted fracture of head of *fibula*	11	Incomplete	12	Sepsis still present
3018	3	S	99	½	Compound fracture of *fibula*, middle third ..	—	—	19	Wound quite superficial
2951	2	S	101·5	∞	Large lacerated wound. Compound comminuted fracture of *fibula*	9	18	34	Wound quite superficial. No sinus
2514	5	S	101·5	∞	Fracture of external malleolus and lower end of *tibia* into joint surface	11	25	36	No sinus
2516	9	S	103	∞	Compound comminuted fracture of *tibia* and *astragalus*. Spread of infection up tendon sheaths	—	—	—	Amputation 19 days after admission
2703	5	G	101	5–10	Compound comminuted fracture of external malleolus and articular surface of *tibia*. Some loose fragments removed	19	39	83	Wound superficial. Some swelling still present
2888	3	S	103	∞	Fracture of lower end of *tibia*. *Ankle-joint* involved and *astragalus* fractured. Two secondary hæmorrhages. Leg amputated	—	—	39	Some sloughing of flaps
					[*Six cases of ankle-joint injuries, complicated by severe tarsal fractures, in which amputation was performed shortly after admission, are not given in detail, as no attempt at conservation was felt to be justified.*]				
2711	4	G	99·4	1	Compound fracture of *scapula*. Muscles involved	4	9	13	Wound clean and sterile. Sinus still present
2690	5	G	99·4	10–20	Compound fracture of vertical border of *scapula*	7	11	14	Wound sterile. Small sinus to site of fracture

Continued on next page.

TABLE OF CASES—*continued.*

T. No.	Days after wound when admitted	G = Gunshot wound S = Shell wound	Temperature °F	Sepsis: No. of bacteria per microscopic field	Wound, Complications, etc.	Disappearance of visible dead tissue, in days	Days taken to obtain sterility	Days under treatment	Condition on transfer
2433	4	G	—	30–50	Compound comminuted fracture of *scapula*. Foreign bodies and loose bone removed. Wound closed by means of clips and sutures	5	11	28	Wound healed, scar soft and supple. Sutured on 15th day
2573	5	G	101	4	Compound fracture of *scapula*. Much comminution. Loose fragments removed	13	28	37	Wound sterile. No sinus
2957	4	S	101	15–20	Dirty through-and-through wound of shoulder. Compound fracture of *scapula*	7	10	13	Entrance wound closed. Exit wound superficial. No sinus
2565	10	S	103·4	—	Foreign body removed from venter of *scapula*, which was fractured. Destruction of glenoid fossa. Humerus subluxated	—	Incomplete	45	Wounds healthy. No sinus
3046	5	S	101	20–30	Compound fracture of *acromion process*, not involving shoulder-joint. Some loose bone and cloth removed on admission	11	16	18	Wounds sterile
2831	3	G	102	30–50	Compound comminuted fracture of shaft of *humerus*. Considerable loss of substance	37	Incomplete	53	Wounds clean. No bone exposed
2587	6	S	100·5	5–10	Compound comminuted fracture of *humerus* ..	15	20	32	Union. No sinus
3054	4	S	99	∞	Compound comminuted fracture of *humerus* ..	22	30	54	Firm union. No sinus
OT59	4	S	103	∞	Very comminuted fracture of upper third of *humerus*. Several sequestra removed	—	75	90	Firm union. Small sinus
3053	5	S	101·5	—	Compound fracture of *humerus* .. .. ,, ,, ,, *clavicle*	17 5	24 17	27 27	Firm union. No sinus Wound healed
2956	4	S	102	30–50	Compound fracture of *humerus*, badly comminuted	25	36	92	Union. No sinus

Foreign body removed on admission

2955	5	S	99	1	Compound fracture of lower end of *humerus*. Bone fractured in two places	11	12	20	Wounds sterile and quite small
2950	3	S	102	∞	Compound comminuted fracture of lower third of *humerus*	14	19	30	Wound quite superficial. Firm union
2695	15	S	100	5–10	Compound comminuted fracture of *humerus* ..	7	Incomplete	14	Wounds progressing. Sinus still present
2745	3	G	102	10–15	Compound fracture of *humerus*	5	Incomplete	21	Wounds healthy. Fracture in good position. Sinus still present
2622	6	S	101	10–20	Compound comminuted fracture of *humerus* middle third	5	Incomplete	9	Wound healthy. Sinus to bone
2587	6	G	100·2	5–10	Compound comminuted fracture of *humerus*, communicating with joint	6	18	32	Union. No sinus
2569	6	S	100·2	2	Compound fracture of internal condyle of *humerus*	11	Incomplete	23	Wound healthy. Sinus still present
2554	4	G	99	2	Compound comminuted fracture of lower third of *humerus*	15	20	32	Union. No sinus
2821	3	G	102	30–50	Large wound on outer side of upper arm. Compound comminuted fracture of *humerus*. Much loss of substance	25	32	53	Wound superficial. No sinus. Slight union
2763	3	S	100	—	Compound comminuted fracture of upper end of *humerus*. Ulnar paralysis. Severe secondary hæmorrhage 16th day after admission. Large abscess developed in axilla 26th day. Extensive necrosis of upper fragment. Amputation through shoulder-joint. Death	—	—	28	—
2844	4	S	100	∞	Compound fracture of lower third of *humerus*. Foreign body removed	20	30	42	Wounds quite superficial. Good callus formation. Union
2899	4	S	101	∞	Large wound on posterior aspect of middle third of arm. Compound comminuted fracture of *humerus*	10	13	30	Wound closing rapidly, dry, clean, and superficial

Continued on next page.

TABLE OF CASES *continued.*

T. No.	Days after wound when admitted	G = Gunshot wound S = Shell wound	Temperature °F	Sepsis: No. of bacteria per microscopic field	Wound, Complications, etc.	Disappearance of visible dead tissue, in days	Days taken to obtain sterility	Days under treatment	Condition on transfer
2801	6	S	103	∞	Large muscle wounds of upper arm. Extremely comminuted fracture of *humerus*. Also left-sided hæmothorax	14	Incomplete	57	Wounds clean. Small sinus. ? sequestrum. Fairly firm union
2679	5	S	102	20–30	Extensive lacerated wounds of upper arm. Considerable destruction of all heads of triceps. Musculospiral nerve exposed. Compound fracture of *humerus*	14	Incomplete	86	Wounds closing. Persistent sinus. Some sequestra present
2992	2	S	100	20–30	Perforating wound. Partial fracture of lower third of *humerus*	10	22	26	Wound superficial and sterile
2721	4	S	99·6	20–30	Compound fracture of *humerus* just above olecranon fossa	10	13	46	Union firm. No sinus to fracture
2641	2	G	103	∞	Compound fracture of lower end of *humerus*, involving elbow-joint	30	63	96	Small sinus. Slight union
2546	11	S	104	30–50	Wound on anterior aspect of arm, 3 × 4 in., communicating with wound on upper part of forearm, 7 × 4 in. Comminution of lower end of *humerus*, involving *elbow-joint*	75	82	86	Some flexion possible at elbow
2789	2	S	103	∞	Wound of *elbow-joint*. Comminution of *ulna* and lower end of *humerus*. Several secondary abscesses. General condition at one time serious	60	90	104	Wound superficial and clean. Some movement
2954	32	S	101	2	Wound penetrating right *elbow-joint*. No bony injury	7	10	14	Wound clean, sterile. Small sinus
2466	6	G	100·8	5	Compound fracture of *ulna* at elbow and wrist. *Wrist-joint* and *elbow-joint* involved	46	60	81	Wounds clean, sterile. No sinus
2598	4	S	100	∞	Compound comminuted fracture of upper end of *ulna*	40	Incomplete	57	Elbow still slightly swollen. Wound nearly healed

									lating surface. No sinus
2680	5	G	100	20–30	Compound comminuted fracture of *ulna* ..	5	8	9	Wound clean. Sinus to bone
2622	6	S	99·4	3	Compound fracture of *ulna* and *radius* ..	3	6	9	Wound covered with clean granulations .
2591	4	S	99·8	5–10	Compound comminuted fracture of middle third of *ulna*	5	7	10	Wound healthy. Small sinus to bone. Letter received saying wound completely healed 27 days after evacuation
2501	5	S	100·8	∞	Compound fracture of lower end of *ulna*. Nerve divided. Loss of substance	15	37	40	Wound clean and ready for suture. No sinus
2691	7	S	100·6	20–30	Extensive wound on extensor and flexor aspects at junction of middle and lower thirds of right forearm. Compound fracture of *ulna* and *radius*	16	34	41	Wound clean and granulating
2636	2	S	101·2	∞	Compound comminuted fracture of *radius*. Pieces of loose bone removed	7	37	40	Wound healthy. Sinus to bone
2716	8	S	100	5	Oblique fracture of middle third of *radius* ..	7	Incomplete	13	Wound almost sterile. Sinus to bone
2570	6	S	99·6	20–30	Compound fracture of *radius* just below neck. Much laceration of muscles	8	10	15	Wound clean. Small sinus to fracture
2518	7	S	101	30–50	Multiple perforating wounds. Compound fracture of middle of *radius*	12	14	40	Wounds sutured. Primary union
2509	4	S	102	∞	Comminuted fracture of *radius* below neck. Compound fracture of *ulna*. Extensor muscles lacerated, tendons exposed	11	25	40	Wound clean and closing in rapidly. Sinus to fracture
2411	5	S	101	∞	Compound comminuted fracture of lower third of *radius*. Much loss of substance	15	42	65	Wound clean and granulating. No sinus
2731	5	S	99·4	5–10	Compound comminuted fracture of middle third of *ulna*	4	Incomplete	10	Wound almost sterile. Sinus to fracture

Continued on next page.

TABLE OF CASES—*continued.*

T. No.	Days after wound when admitted	G = Gunshot wound S = Shell wound	Temperature °F	Sepsis: No. of bacteria per microscopic field	Wound, Complications, etc.	Disappearance of visible dead tissue, in days	Days taken to obtain sterility	Days under treatment	Condition on transfer
2600	3	S	102	4	Large wound involving whole *carpus* and part of *metacarpus*	37	52	92	Wound superficial. No sinus
3017	18	S	100	5–10	Multiple wounds. Compound fracture of external *carpal* bones	10	18	26	Wound small. Granulations. Bones covered over
2518	7	S	101	∞ tetanus	Large wound involving whole of *radiocarpal joint*. Bones shattered	8	60	40	Wound superficial and sterile
2466		G	100·8	5–10	*Ulna* exposed and fractured. Pieces of *carpal* bones removed	15	52	81	Wound clean and sterile. No sinus
2635	3		100·8	∞	Comminution of *metacarpals* and *carpus*, with involvement of *wrist-joint*	23	34	54	Wound closed. No communication with joint
2903	5	S	102	∞	Extensive wound of inner aspect of wrist and forearm. Fracture of lower end of *ulna* and *carpus*	37	Incomplete	56	Wounds granulating. Small sinus
2840	2	G	100	∞	Compound fracture of lower end of *ulna* and of *carpus*. Some loose fragments removed on admission	30	44	65	Exit wound closed. Entrance wound superficial. No sinus
2503	5	S	102·8	½	Compound fracture of *phalanx* of second finger	10	12	40	Wound closed. No sinus
2589	8	G	103·4	3	Multiple wounds of right hand. Index finger absent. Palm lacerated. Compound fracture of *metacarpal*	6	Incomplete	11	Wounds healthy. Sinus present
2474	4	G	101·6	∞	Outer four *metatarsals* exposed and fractured. Amputation of foot 30 days after admission. Complete disorganization of tendons and muscles	—	—	—	Stump clean. Healing well
2451	12	G	100·4	∞	Fracture of 4th and 5th *metatarsals*	25	Incomplete	48	Wound healthy. Sinus

2511	8	S	105	15–20	Compound fracture of middle phalanx of second [illegible]	[illegible]	[illegible]	[illegible]	[illegible] sinus
2427	3	G	100·4	∞	Large wound removing big toe, all *phalanges* of hallux removed, part of *metatarsal* exposed. Exposed metatarsal removed	35	41	59	Wound sutured. Sutures removed
2971	4	S	100	10–15	Compound comminuted fracture of *os calcis*. Some loose bone removed	13	17	26	Wound quite lean and dry. No sinus
2740	3	S	103	10–15	Compound fracture of *sacrum*	10	18	24	Wounds clean. Small sinus
3008	3	S	99	5	Wound of right buttock. Compound fracture of *ilium*. Foreign body removed from pelvis	6	11	13	Wound quite dry and sterile
2453	6	G	99	2	Compound fracture of crest of *ilium* and of spinous processes of *lumbar vertebræ*	10	15	52	Sutured 30th day after admission
2775	3	S	102·4	∞	Large wound, inclined to bleed, passing down to *ilium*. Foreign body removed. Two secondary hæmorrhages from gluteal artery. Internal iliac tied. Dakin solution discontinued	26	Incomplete	42	Buttock wound almost sterile and very healthy
2737	4	G	102	10–15	Large wound of left buttock, involving anus and external sphincter. Colostomy performed	11	Incomplete	35	Wound clean
2864	4	S	101·4	∞	Large wound, 3 × 2 in., on right side of vertebral column at level of sacro-iliac joint. Bone exposed	10	Incomplete	25	Wound cleaning slowly. General condition good
2791	4	G	102·4	2	Entrance wound on inner aspect of thigh. Exit through buttock	5	10	12	Wound clean and sterile
2771	7	S	101·6	∞	Wound passing down to and through *ilium*. Foreign body not found	4	Incomplete	7	Wound healthy. Sinus to bone
2446	5	S	99·6	30–50	Wound of buttock, 3 in. deep, leading to posterior aspect of *ilium*	33	36	38	Wound clean. Deep sinus still present
2428	5	G	—	5	Small buttock wound, with sinus about 2 in.	4	8	28	Wound sewn up. Primary union 11th day
2432	6	G	—	20–30	Wound of left buttock	4	7	12	Wound closing
OT50	6	S	103·2	30–50	Entrance wound in left buttock. Metal fragment removed at C.C.S.	10	Incomplete	11	Wound much cleaner

GUNSHOT WOUNDS OF THE KNEE-JOINT: A REPORT ON 100 CONSECUTIVE CASES.

By Captain E. TISSINGTON TATLOW, R.A.M.C. (T.)

During the past twelve months, the treatment of gunshot wounds of the knee-joint at the clearing stations has improved very considerably, thus simplifying the problems presented to the surgeon at the base hospital. This improvement must be attributed largely to earlier operation, complete removal of damaged and infected tissue, and in consequence the ability to close the wounded joint completely. At one time it was a rare event to see a case of a grossly injured knee-joint admitted at the base completely sutured; of recent months this is almost the rule.

STATISTICAL SUMMARY.

The cases in this series have been under my treatment at a base hospital this year. Of the 100 cases, 2 died, both after amputation; 4 were successfully amputated; 9 were successfully resected; and 12 were unoperated upon. The remaining 73 were evacuated to England, after operation either at the base or at the clearing station, with a normal temperature, and either healed or granulating wounds, or at most a small discharging sinus.

Varieties of Lesion.—The lesions of the knee-joint may be grouped under five headings, referred to in detail below, as follows:—

Tear of the capsule only	9 cases
Through-and-through wound without bone injury ..	13 ,,
Through-and-through wound with bone injury	25 ,,
Retained foreign body in the joint without bone injury ..	24 ,,
Retained foreign body with bone injury	29 ,,

Missile.—With regard to the nature of the projectile, the figures are as follows:—

Revolver bullet	1 case
Machine-gun bullets	4 cases
Rifle bullets	9 ,,
Shrapnel balls	9 ,,
High-explosive fragments ..	77 ,,

The term 'high-explosive fragment' is used to include fragments of shell, bombs, and grenades.

Organisms.—Cultures of the fluid of the joint were made in 37 cases, with the following results:—

No organisms grown	17 cases
Streptococci	13 ,,
B. perfringens	3 ,,
Staphylococcus aureus	2 ,,
Staphylococcus albus	1 case
Diphtheroid (? contamination) ..	1 ,,

It is of interest to consider the results of the 13 cases found to have a general streptococcal infection of the joint: 5 were resected; 5 were amputated; 2 had resections of the patella; 1 had Carrel-Dakin treatment and drainage. In the total series, only 11 cases were resected and 6 amputated, so the streptococcal infection may be seen to account for a large proportion of these.

Of the 3 cases infected by the *B. perfringens*, in 2 the joint was resected: in 1 a high-explosive fragment was removed, followed by B.I.P.P. treatment and suture. One case which was resected had, in addition to the *B. perfringens* infection, a severe fracture of the intercondylar notch, in which a large high-explosive fragment was imbedded.

Tear of the Capsule only.—9 cases.

Amputation	2
Resection	1
B.I.P.P. and suture ..	5
Salt pack	1

The two amputations and the resection were not diagnosed as being penetrating wounds of the knee-joint for some days after their being wounded. All the three were infected by the streptococcus.

Through-and-through Wound without Bone Lesion.—13 cases.

No operative treatment	9
Excision of wounds and suture ..	4

Foreign Body in the Joint and no Bone Lesion.—24 cases.

Removal of the missile, B.I.P.P., and suture ..	6
Removal of the missile, lavage, and suture ..	6
Carrel-Dakin treatment	2
Formalin and glycerin injections	2
No operative treatment for removal	7
Salt pack	1

Bone Lesion involving the Knee-joint.—54 cases.

Compound fracture of the patella	11
Fracture of the shaft of the femur	5
Fracture of both condyles	3
Fracture of a single condyle..	20
Fractuıe of the head of the tibia	10
Fracture of the internal condyle and the outer head of the tibia..	1
Fracture of the patella, external condyle, and outer head of the tibia	1
Fracture of the patella and the inner head of the tibia ..	1
Fracture of the patella and both condyles	1
Fracture of the patella and the intercondylar notch	1

Wounds of the Joint involving the Patella.—11 cases.

Resection of the patella	4
Suture of the patella fragments	1
Cases treated conservatively after toilet, foreign body removal, and suture of capsule	6

The four cases of the resection of the patella are reported to be walking, with stiff knee-joints. The case of patella suture resulted in ultimate necrosis of the patella, with a stiff knee.

Wounds of the Joint involving the Shaft of the Femur.—5 cases.

One had a rifle bullet in the shaft.

A final report has only been received concerning two of these cases. Both have mobile knee-joints.

Wounds of the Joint involving Both Condyles.—3 cases.

Treated conservatively	..	1
Resection of the joint	..	2

Both resections had bony union on evacuation. One was performed for fracture of the condyles and intercondylar notch, with *B. perfringens* infection; the other was a primary resection for severe comminution of both condyles, performed at the clearing station seven hours after the time of wounding.

Wounds of the Joint involving One Condyle.—20 cases.

a. External condyle.—7 cases (slight bone injury 4; severe 3).

Treated conservatively	..	4
Amputation ..	..	1
Resection of the joint	..	2

Two were evacuated with minute foreign bodies remaining in the condyle.

b. Internal condyle.—13 cases (slight bone injury 4; severe 9).

The entire series were treated conservatively. One was evacuated with a shrapnel ball remaining in the condyle, and one with multiple high-explosive fragments in the joint.

Wounds of the Joint involving the Head of the Tibia.—10 cases (severe bone injury 3; slight 7).

Amputation ..	..	1 (died)
Joint resection ..	..	2
Treated conservatively	..	7

Wounds of the Joint involving Several Bones.—5 cases.

Two of these were amputated: one a case of fracture of the patella, the external condyle, and the outer head of the tibia (in this case osteomyelitis of the shaft of the femur developed); the other a case of fracture of the patella and both condyles (here an acute streptococcal arthritis was present). Two other cases are reported to have a fair degree of mobility and to be good functional results: one a case with a severe fracture of the internal condyle and of the outer head of the tibia; the other a case of a fracture of the patella and the head of the tibia. The fifth case, a fracture of the patella and the intercondylar notch, is still in the hospital; the patella was resected at the casualty clearing station, and the bone cavity treated with B.I.P.P.

Thus, of the 54 cases with a bone lesion, 1 died after amputation, 4 were successfully amputated, and 7 had resections performed; all the resections have been evacuated to England with good union, and 3 are reported to be walking well. Of the other 42 cases evacuated on their splints, 13 reports have been received: 7 cases have stiff, useful knee-joints (4 of these were cases of resected patella, 1 a case of fractured patella which was sutured and subsequently necrosed, 1 was a case of a fractured condyle); 7 cases

are reported to have mobile knee-joints (2 were fractures of the shaft of the femur, 1 was a fracture of the patella and head of the tibia, 1 was a fracture of the internal condyle and the head of the tibia, 2 were fractures of the internal condyle, and 1 was a fracture of the head of the tibia only).

Of the 100 cases, 12 did not undergo any operation. Of these, 10 were cases with through-and-through wounds (3 of these had fractures of the shaft of the femur, 1 had a fracture of the head of the tibia, and 1 a fracture of the condyle): 2 of the cases had retained foreign bodies (one, a shrapnel ball in the internal condyle; the other, multiple minute high-explosive fragments in the joint). In 6 the wounds were caused by rifle bullets, in 3 by shell fragments, in 2 by machine-gun bullets, and in 1 by a shrapnel ball.

In the series, 68 cases were operated upon at the clearing stations. Of these, 35 were completely closed; these cases required no further operative treatment, with two exceptions—in one case a revolver bullet was left in, and had to be removed; in another, a general infection of the joint with the *Staphylococcus aureus* supervened, necessitating opening up.

Of the 34 cases operated on at the base, 14 had had a previous operation at the clearing station; 20 had had no operative treatment. Of the 20 cases unoperated upon at the clearing station, 3 were amputated, 5 resected, 2 had resections of the patella, 6 had operations for the removal of foreign bodies, 1 had wound enlargement, 1 had a tear in the capsule excised and sutured, 1 had an exploratory operation, and 1 was treated by repeated aspirations. Of the 14 cases which had been previously operated upon, 2 had foreign bodies removed which the casualty clearing station had failed to find, 3 were amputated, 4 had open wounds which had to be enlarged, 1 had an abscess evacuated outside the joint, 1 had a sutured joint opened up, and 3 were resected.

That is to say, the clearing stations sent down 100 cases of gunshot wound of the knee-joint; 68 had been operated upon there—of these, 14 required re-operation; 32 were unoperated upon—of these, 20 required operation.

TREATMENT.

I propose briefly to discuss some of the problems which arise in connection with gunshot wounds of the knee-joint at the base hospital.

Some of the cases arrive, several days after being wounded, with the foreign body in the joint, either with or without a fracture. Is the foreign body to be removed or to be left in? The answer must depend on the size of the missile and its situation. A foreign body deep in the shaft of the femur, or in a condyle, or the head of the tibia, in a case where the joint is quiescent, can well be left alone. Where there is a large foreign body free in the joint, or protruding out of the bone into the joint cavity, it must be removed.

The question then arises: Should the missile be removed at once, or should an expectant attitude be adopted, and the foreign body removed weeks or months later when the joint is 'quiet'? It is impossible, of course, to make an absolute rule, but my practice has been to remove any such foreign body of large size immediately. The operative procedure has included excision of

the track, employment of a fresh set of instruments for the removal of the foreign body, a gentle mechanical flushing of the area in which it lay, the placing of a small quantity—about 15 grains—of bismuth, iodoform, and paraffin paste into the joint and, whenever possible, the suturing of the capsule and the entire closing of the wound. Special attention should be paid to any bone injury, and after careful curettage, B.I.P.P. is placed in the resulting bone cavity.

The other most frequent, or at any rate most pressing, problem at the base is the treatment of cases of general arthritis of the streptococcal variety. Such cases, when treated by a posterior drainage operation—more especially when there was a bone lesion—did badly in my hands, and in the present series I have attempted resection of the joint rather than this form of drainage. The resection includes the patella, but all the synovial membrane possible is left to act as a protective barrier. After resection, the operation area is treated with B.I.P.P., extension is applied, and a gauze pack is placed between the bone ends. After a lapse of some three to seven or even ten days, depending on the pulse-rate and general condition of the patient, the pack is taken out under nitrous-oxide anæsthesia, the extension removed, and the bony surfaces are allowed to come together. Some cases, after the removal of the pack, have required irrigation daily for suppuration about the resection; but with the exception of two cases amputated, to which I shall refer later, this has cleared up, and bony union has resulted. Fixation after resection is important. There is a tendency for the lower end of the femur to slide outwards so that this bone and the tibia are not in the same straight line. This displacement can be overcome by the use of a short Robert Jones crab splint, in which the limb rests, and which is itself placed on a Thomas hip splint. For this suggestion I am indebted to Captain R. C. Harkness. Osteomyelitis has not supervened in any of the cases.

I am only too well aware that resection performed later than the third or fourth day is a 'second best' operation; the ideal procedure would be so to treat every case at the clearing station that secondary resection would be unnecessary. This notwithstanding, it would appear that in the case of a severe streptococcal infection—especially in the presence of a bone lesion—resection gives a more certain result than does posterior drainage.

It would appear to me that in any case where there is a general acute streptococcus infection and a bone lesion, resection is a justifiable operation; and even in the cases where there is an acute infection of the long-chain streptococcus variety and no bone injury, the possibility must be considered of resection being a wiser operation than drainage, even when the latter is carried out by means of Campbell and Woolfenden's method, with division of the heads of the gastrocnemius (*vide Lancet*, 1917, Aug. 11, 185).

Acute arthritis due to the staphylococcus group can easily be treated by simple drainage methods. Where there is no bone injury, simple incision usually suffices; if there is a bone injury, Carrel-Dakin treatment to the site of such injury gives the best results.

Cases of pure *B. perfringens* infection of the joint are very amenable to treatment; usually, after foreign-body removal and lavage, these joints can be sutured.

Pyæmic infection of the knee-joint by the streptococcus or other organism can be successfully treated by incision, mechanical lavage, the application of 15 gr. of B.I.P.P., suture of the capsule, and skin closure.

Aspiration has given bad results in my hands, both in 1916 and in the few cases thus treated in this series. If the effusion is sterile, it must be regarded as a protective effusion and left alone; if it is infected, it must be evacuated. Aspiration should not be used as a curative measure. Every effusion is needled for diagnostic purposes, and if sterile, is left alone to be absorbed, being considered a protective effort on the part of the joint. Non-absorption does not occur.

It seems necessary to repeat what several other observers have noticed, namely, that absolute immobility is necessary. The fewer the dressings the better. Any operative procedure, short of resection, should be carried out without removing the limb from the splint. Every case of wound in the joint is best treated, for a time at any rate, on a Thomas splint with a fixed extension, using pulleys or not for the splint itself, as may seem advisable.

Starting pains at night are an indication for tightening the extension. At first, if the joint appears quiescent and no pain is complained of, the limb is placed on the splint, and the extension bands are applied, but not tightened; as soon as the knee 'jumps,' the bands must be tightened. Small plates of perforated zinc laid on cross-ribbons of aluminium are the best supports, as they can be easily changed and the skin attended to by the ward sister with the minimum of movement. A Balkan support is necessary.

CONCLUSIONS.

1. Early operation, if the procedure be radical, and especially if the entire capsule can be sutured, results, in 94 per cent of the cases, in a sterile joint, and therefore in a successful issue.

2. Where a pack or drain is used down to a tear in the capsule or to a cavity in bone, the results can never be depended upon.

3. The removal of missiles from the joint within the first week. even in the presence of sepsis (other than that due to the streptococcus), can be followed by immediate suture, B.I.P.P. being used to aid sterilization.

4. The Carrel-Dakin method is most useful for the treatment of bone lesions or septic peri-articular conditions. It is almost impossible to sterilize a severely infected joint by this method.

5. In the presence of a general infection of the joint by the streptococcus, resection gives good results, even when performed in the second or third week.

6. Cases with a severe bone injury should be treated more often than they are by an immediate primary resection of the joint at the clearing station.

[*The semi-diagrammatic figures illustrating the article are made from the outlines of x-ray plates.*—Ed. Sec.]

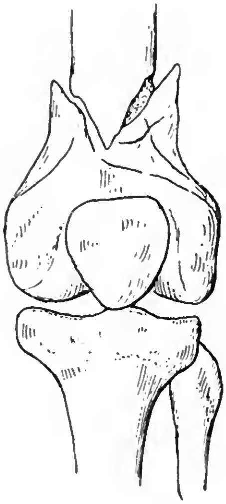

Fig. 363. — *Case* 3. Rifle-bullet wound. Severe comminuted fracture of femur above condyles.

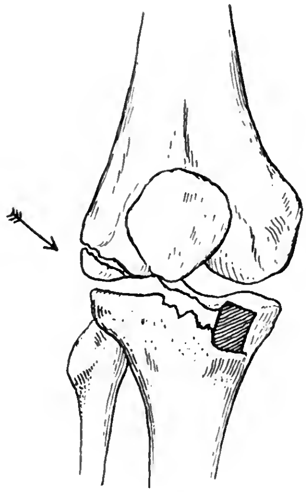

Fig. 364. — *Case* 6. Large high-explosive fragment passed through condyle and joint and lodged in head of tibia.

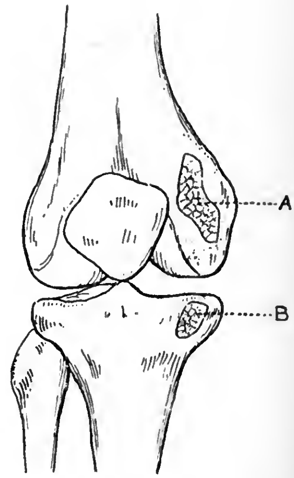

Fig. 365.—*Case* 9. Wound by high-explosive fragment, exposing cancellous tissue of internal condyle and inner head of tibia. A. Cavity in femur. B. Cavity in tibia.

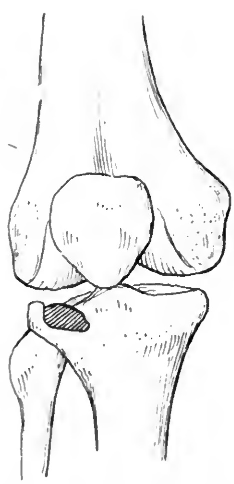

Fig. 366.—*Case* 10. High-explosive fragment in outer head of tibia after passing through joint.

Fig. 367. — *Case* 13. Patella completely divided by high-explosive fragment.

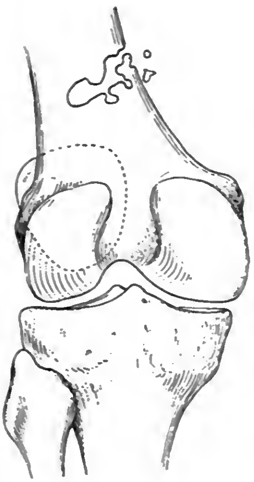

FIG. 368.—*Case* 16. Partial fracture of shaft of femur by machine-gun bullet.

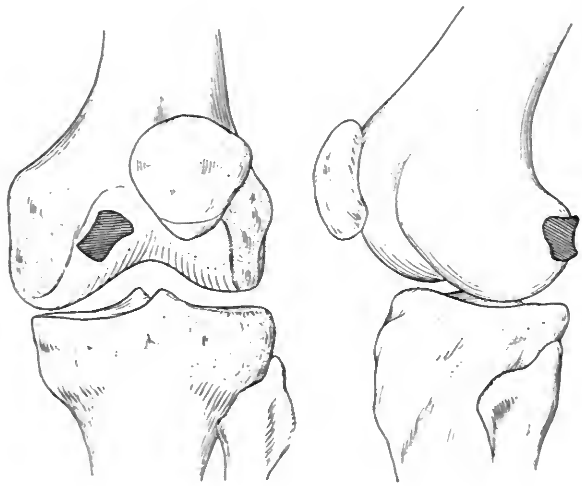

FIG. 369.—*Case* 21. High-explosive fragment lodged in internal condyle of femur posteriorly.

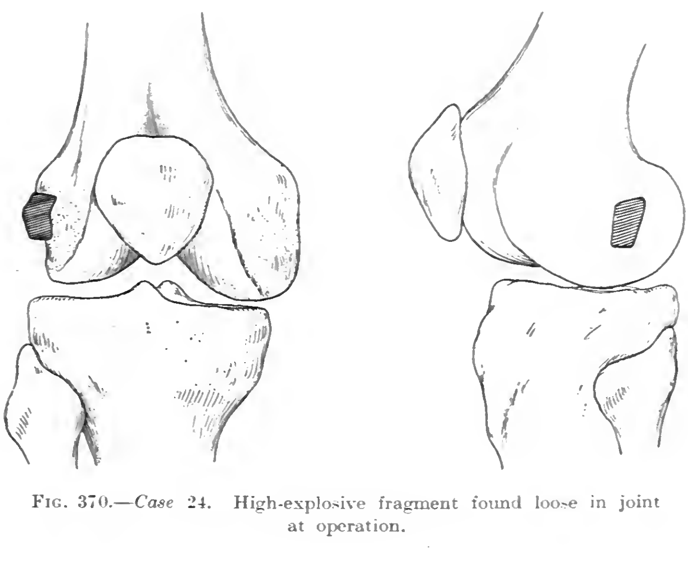

FIG. 370.—*Case* 24. High-explosive fragment found loose in joint at operation.

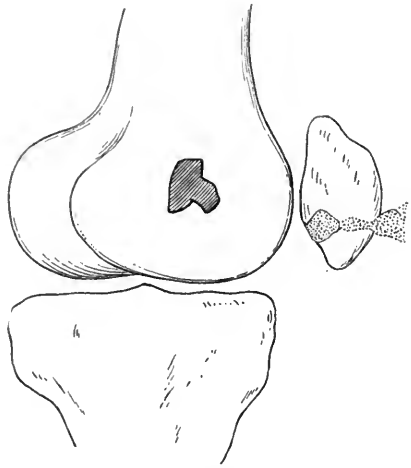

FIG. 371.—*Case* 26. Large high-explosive fragment lying in internal condyle of femur. B.I.P.P. in superficial track.

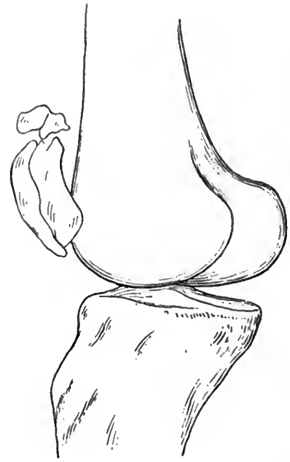

FIG. 372.—*Case* 46. Fracture of patella by a large high-explosive fragment. The missile has been removed.

FIG. 373.—*Case* 51. Large high - explosive fragment lodged in intercondylar notch.

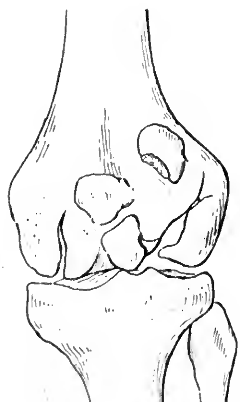

FIG. 374.—*Case* 55. Fracture of patella and both condyles by high-explosive fragment.

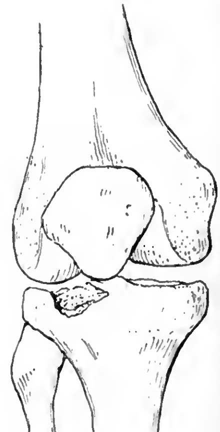

FIG. 375.—*Case* 56. Fracture of outer head of tibia by rifle bullet.

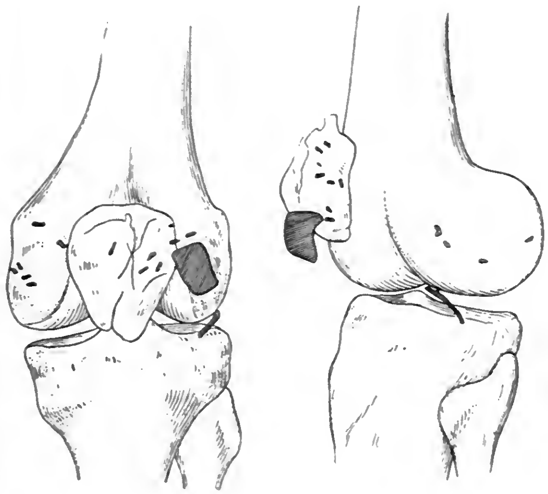

FIG. 376.—*Case* 57. Fracture of patella by revolver bullet, showing bullet and many fragments of lead in joint.

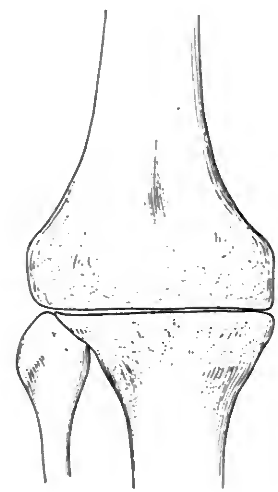

FIG. 377.—*Case* 79. Resection of joint after high-explosive shell wound.

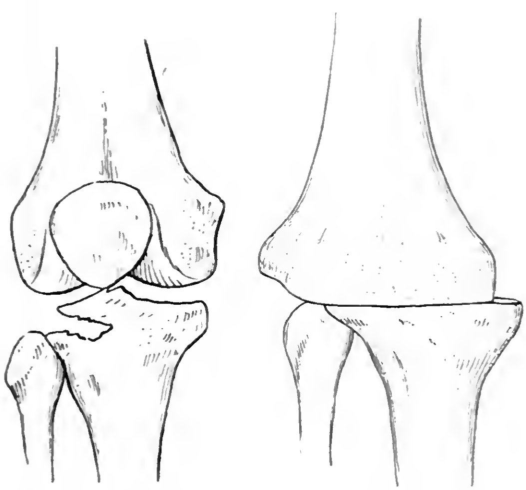

FIG. 378.—*Case* 61. Fracture of tibia by high-explosive fragment which traversed the joint and lay deeply in the outer head. The left-hand illustration shows the joint after removal of the fragment and before resection, the right-hand one the joint after resection, and the outward displacement of the femur which followed it.

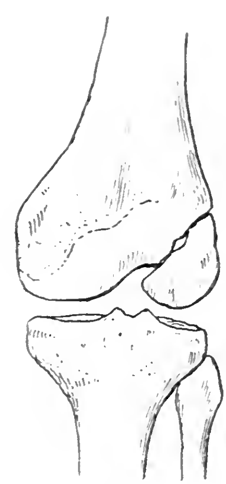

FIG. 379. — *Case* 82. Complete fracture of external condyle by high - explosive fragment.

CASES OF RESECTION OF THE KNEE-JOINT.

Case No.	Nature of Injury	Preliminary Operative Measures	Days from Wounding to Resection	Organisms Found	Result
10	High-explosive fragment lodged in outer head of tibia	Removal on 4th day	8	Streptococcus	Walking well without support
19	Shrapnel ball lodged in external condyle	Removal on 4th day; bony cavity treated with B.I.P.P.	10	Streptococcus	Amputation
20	Large tear of the capsule, exposing condyle and patella	Drainage and irrigation with Dakin's solution 4th day	19	Streptococcus	Amputation
23	Large tear of vastus externus and small perforation of joint capsule	Drainage and lavage 6th day	8	Streptococcus	Good bony union on evacuation. Walking well without support
35	Multiple high-explosive shell wounds into the knee-joint	Aspiration and injection of formalin and glycerin 11th day. Ditto 12th day. Lateral and posterior incisions for drainage 14th day. Carrel-Dakin treatment	37	Streptococcus	Evacuated to England with bony union. Now discharged from the army and walking well; 2 in. of shortening
51	High-explosive fragment lodged in inter-condylar notch with fracture of condyles	Nil	3	*B. perfringens*	Bony union on evacuation
61	High-explosive fragment lodged in head of tibia	Removal 10 hours after wounding. Treatment with B.I.P.P. and pack	5	Streptococcus	Had fibrous union on evacuation. (See *Fig.* 378)
78	Compound comminuted fracture of both condyles	Nil	7 hours	(?)	Evacuated to England with fibrous union
79	Large wound outside and above right patella. Capsule torn. High-explosive fragment lodged in external condyle	Casualty clearing station failed to find. Removal 4th day	48	1. *B. perfringens* 2. Secondary mixed infection	Good alinement and fibrous union on evacuation. (See *Fig.* 377)
82	Complete fracture of external condyle	Removal of condyle 9th day	12	Streptococcus	Fibrous union
95	Fragment lodged in anterior surface of internal condyle. Wound of entrance in popliteal space	Removal of fragment on 2nd day	18	*Staphylococcus aureus*	Evacuated to England in good position with fibrous union

CASES AMPUTATED.

Case No.	Nature of Lesion	Organisms Found	Early Treatment	Reasons for Amputation	Result
19	Shrapnel ball lodged deeply in external condyle	Strepto-cocci	Shrapnel ball removed 5th day. Resection of joint 11th day	Patient developed confusional insanity with melancholia. Amputation performed, as he was considered to be a bad subject for the lengthy treatment necessitated by resection	Evacuated with clean amputation stump
20	Large lacerated wound to outer side of knee-joint, with exposure of external condyle and patella. Multiple wounds of calf	Strepto-cocci	Excision of wound and Carrel-Dakin treatment at casualty clearing station on same day as wound. Joint involvement not appreciated. On 4th day, when at base, multiple incisions in calf for *B. perfringens* infection. High-explosive fragment removed. Joint irrigated. Resection on 20th day. Amputation 39th day	Necrosis of bared lower end of femur was the ground for amputation. Possibly a higher section of the femur might have resulted in successful resection	Stump healed on evacuation
30	High-explosive fragment traversed patella, fracturing external condyle, and also outer head of tibia	(?)	Resection of patella. Wide removal of damaged bone. Treatment with B.I.P.P. and pack on same day as wound. 7th day, when at base, pack removed. 23rd day, sequestra removed. 25th day, amputation	Chronic osteomyelitis of shaft of femur and head of tibia	Amputation stump healed
41	Large lacerated area of muscle on inner side of right knee-joint. Wound of chest wall and compound fracture of left clavicle	Strepto-cocci	The clearing station surgeon excised the lacerated tissue, but failed to observe involvement of knee-joint. 5th day, when at base, joint opened by lateral and posterior incisions. Flavine irrigation. Capsule not sutured. On 8th day, amputation. 11th day, death	Extreme degree of sepsis	Post-mortem examination revealed duodenal ulcer, with a severe hæmorrhage
55	Penetration of the left knee-joint by high-explosive fragment; with compound fracture of both condyles	Strepto-cocci	2nd day, removal of foreign body and portion of external condyle; Carrel-Dakin treatment. 18th day, when at base, amputation	General condition very poor. Extensive tracking of pus both up the thigh and down the calf	Amputation flaps still open on evacuation
56	Rifle bullet entered to outer side of right patella, fractured outer head of tibia, and emerged low in popliteal space	Strepto-cocci	Joint opened on 8th day at clearing station by anterior incisions. Eusol lavage. B.I.P.P. applied and capsule sutured. Wound of exit enlarged slightly. 25th day, when at base, posterior drainage, with division of outer head of gastrocnemius. 28th day, amputation. 30th day, direct transfusion of 650 c.c. blood. 35th day, evacuation of pyæmic abscess of left knee-joint. 41st day, evacuation of pyæmic abscess of left shoulder-joint. 44th day, death	Immediate amputation on admission was considered advisable, but patient absolutely refused. It was only two days after the posterior drainage operation that he consented to amputation	At the post-mortem, osteomyelitis of the shaft of the femur was found, and some pus in the left shoulder-joint. The left knee-joint appeared clean

PARTICULARS

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
1	23.3.17	High - explosive fragment the size of a split pea	Fragment entered to the outer side of the left patella, traversed the suprapatellar pouch, and lay in the quadriceps	—	Wound excised. Joint irrigated and closed. Fragment not found. B.I.P.P. applied. Wound closed
2	28.2.17	Rifle bullet	Foul-smelling transverse wound, laying open the front of the right knee-joint and fracturing the patella. Much pus in the cancellous tissue of the patella and in the joint	Strepto-cocci	Salt pack
3	14.2.17	Rifle bullet	Through-and-through wound. Entrance 1 in. above and to the inner side of the left patella. Exit to outer side of popliteal space. Severe comminution of femur above condyles. (See *Fig.* 363)	—	Back splint
4	21.3.17	High-explosive shell	Through-and-through wound of left supra-patellar pouch. Entrance above and to outer side of patella. Exit through biceps femoris	—	Track excised. Entrance wound sutured. Exit wound packed
5	20.3.17	High-explosive shell	Penetrating wound, outer side of left knee. Fragment lying in supra-patellar pouch	—	Wound excised. Foreign body removed. Joint lavage. Suture of capsule. B.I.P.P. applied. Skin suture
6	28.3.17	High-explosive shell	Large fragment perforated the right external condyle, traversed the joint, and lodged in the inner head of the tibia. (See *Fig.* 364)	—	Wound of entrance excised, external condyle trimmed, and fragment removed from inner head of tibia. Joint lavage and treatment of wound with B.I.P.P. Complete closure
7	28.3.17	High-explosive shell	Fragment entered right suprapatellar pouch externally	—	Wound excised. Fragment removed. Eusol lavage. Capsule sutured. B.I.P.P. applied. Skin closure
8	27.3.17	High-explosive shell	Large entry wound, 8 in. long, on outer side of right thigh. Fragment lay on internal condyle. Large tear of joint capsule	Strepto-cocci	Large area of vastus externus and quadriceps excised for gas gangrene. Counter-incision made over internal condyle. Fragment removed. Drainage tube, ½ in. in diameter, passed through the joint. Massive salt pack applied
9	31.3.17	High-explosive shell	Entrance above and to inner side of right patella, entering joint, exposing cancellous tissue of internal condyle and of the inner head of the tibia. (See *Fig.* 365)	—	Excision of wound. Condyle laid bare. Salt pack
10	9.4.17	High-explosive shell	Entrance wound at level of centre of right knee-joint externally. High-explosive fragment lodged in outer head of tibia, traversing joint and cartilage on its way. (See *Fig.* 366)	Strepto-cocci	Nil

OF CASES.

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
Same day	Extension and Thomas splint applied	Nil	10.4.17. No effusion. Temperature normal. Wound healed. Fragment *in situ*	—
Six days	6.3.17. Resection of the patella. Operation area douched with saline. 15 gr. of B.I.P.P. applied. Partial suture	24.3.17. Small extension abscess in vastus externus	24.4.17. Wound granulating. No discharge. No effusion. Temperature and pulse normal	Stiff knee
—	Thomas splint and extension applied	Nil. Sequestra removed in England	15.4.17. Bony union in good position. Wounds still discharging	Can flex knee to a right angle
Same day	Pack removed	—	8.4.17. No effusion. Wounds granulating. Suture line healed. Temperature normal	—
Same day	Nil	Nil	8.4.17. Wound healed. No effusion	—
One day	Extension applied	Nil	Wound healed by first intention. Temperature and pulse normal	6.6.17. Some mobility of joint. Walking without crutches
One day	14.4.17. Abscess outside the joint opened	Extensive abscess in vastus externus	18.4.17. No effusion. Wound granulating. Temperature normal	—
One day	Salt pack removed. Large quantity of pus tracking in every direction. 3.4.17. Operation. Wounds cleansed. Carrel's tubes placed in position. 25.4.17. Counter-opening on inner side of thigh for continued suppuration	Through-and through wound of right loin. Collapse of both lung bases	18.5.17. Wounds granulating. Temperature normal	27.8.17. Stiff knee. Walking well
Same day	Pack removed. Carrel-Dakin treatment for three weeks	Nil	7.5.17. Wound granulating. Temperature normal	Wound healed. Mobility to 40°. Walks well
Four days	13.4.17. High-explosive fragment removed. Cavity treated with B.I.P.P. 16.4.17. Resection of knee-joint	Nil	11.5.17. Wound healed except at external extremity of incision. Bony union	19.7.17. Ankylosed knee. Good result. Still using crutches. 4.9.17. Walking without crutches

Continued on next page.

PARTICULARS OF

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
11	9.4.17	High-explosive shell	Large spear-shaped fragment perforated right knee-joint just below patella, and remained protruding through skin. Removed at field ambulance	*Staphylococcus aureus*	Joint opened and fragment searched for (through an error). Formalin and glycerin injected. Skin sutured
12	9.4.17	Machine-gun bullets	Right knee: entrance wound below and behind head of fibula; exit wound in front of the internal condyle; fracture of condyle, and joint traversed. Left knee: through-and-through anteroposterior wound, entrance anteriorly; fragments of head of fibula blown out through posterior wound; left knee-joint not involved, unless through communication with fibular articulation	—	Salt packs and excision of track. B.I.P.P. to internal condyle. Wound packed. Remainder of wound sutured. B.I.P.P. applied to fractured remains of head of left fibula. Pack applied
13	9.4.17	High-explosive shell	Large irregular gangrenous wound over left knee-joint, with patella completely divided and lying in a pool of pus. (See *Fig.* 367)	Streptococci	Salt pack
14	11.4.17	High-explosive shell	Capsule of left knee-joint torn by fragment of high-explosive shell which penetrated ligamentum patellæ. Fragment fell out after tearing capsule	Sterile effusion	Splinting
15	14.4.17	High-explosive shell	Entrance wound behind head of right fibula. Exit external to patella anteriorly. Laceration of external condyle.	—	(Notes lost.) Anterior exit wound excised and sutured, evidently
16	28.4.17	Machine-gun bullet	Entrance and exit wounds of right suprapatellar pouch. Femur fractured in its inner half but without complete loss of continuity. (See *Fig.* 368)	—	Wounds excised. Capsule sutured. Entrance wound closed. Exit wound packed down to bone
17	14.4.17	Machine-gun bullet	Anteroposterior penetrating wound of left femur above condyles, with two fissures radiating upwards. Entrance 1 in. above patella; exit, popliteal space at same level. Suprapatellar pouch involved	—	Splinting
18	29.4.17	Rifle bullet	Entrance wound just above left patella near mid-line. Bullet lodged in shaft of femur	Exudate sterile	Splinting
19	28.4.17	Shrapnel ball	Entrance wound to outer side of left knee. Ball traversed joint and lodged deeply in external condyle	Streptococci	Nil

CASES—*continued.*

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
Same day	Hyperchlorous washing after removal of stitches	Copious purulent exudate	7.5.17. Small sinus. Temperature normal	25.8.17. Mobile joint. Walks well. 19.9.17. "Will be fit for service in two months"
Two-and-a half days	21.4.17. Salt pack replaced, and again on 26.4.17	Nil	30.4.17. Wound healed, excepting track to internal condyle where fracture lies. Temperature normal. No effusion	—
Three days	Resection of patella. Gangrenous tissue excised. Pus swabbed out of joint and eusol douche used. 15 gr. of B.I.P.P. applied. Partial suture	Chronic suppuration about suture line	28.5.17. Wounds granulating. Temperature normal	28.8.17. Knee stiff. Is walking well
Five days	Wound excised. B.I.P.P., gr. 15, placed in joint. Capsule sutured. Wound closed	High-explosive fragment removed from cavity in left hamstrings	30.4.17. No effusion. Wound healed	12.9.17. Some degree of mobility. Still under treatment
One and a half days	Nil	Entrance and exit wounds of left thigh	26.4.17. No effusion. Wound healed	3.9.17. "Very limited movement in knee; a useful limb"
Eighteen hours	Repacked	Nil	10.5.17. Wound granulating. No effusion	—
—	Nil	—	20.4.17. Temperature normal. No effusion	3.8.17. A perfectly mobile knee-joint. No shortening of limb. Re-classified C3
—	Operation performed owing to x-ray error. Bullet reported in joint, whereas it was in femur. Joint closed. Bullet not removed	—	25.5.17. Wound healed. No effusion. Temperature normal	24.8.17. Good movable joint
Three days	1.5.17. Ball removed. Cavity cleansed. B.I.P.P. applied. Partial suture. 7.5.17. Resection of joint. 24.5.17. Amputation	Patient developed confusional insanity with melancholia. Amputation was done because he was considered to be a bad subject for the lengthy treatment which a resection necessitates	Stump clean	Amputation

Continued on next page.

PARTICULARS OF

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
20	15.4.17	High-explosive shell	Large laceration to outer side of right knee-joint. Condyle and patella exposed. Multiple wounds in calf	Strepto-cocci	Carrel-Dakin, but the fact that the joint was involved was not appreciated
21	3.5.17	High-explosive shell	Entrance wound to inner side of left internal condyle. High-explosive fragment the size of a shilling lying in joint behind internal condyle, which had its cartilage torn. (See *Fig* 369)	—	Nil
22	3.5.17	Rifle bullet	Entrance wound below and internal to inner head of left tibia. Traversed head of left tibia and found exit via ligamentum patellæ; joint penetrated	—	Nil
23	3.5.17	High-explosive shell	Large area of skin removed on outer side of right knee-joint by high-explosive fragment. Vastus externus lacerated. Joint penetrated by a tear of the capsule	Strepto-cocci	Wound cleansed. Penetration of knee-joint not discovered
24	9.5.17	High-explosive shell	Entrance wound to outer side of right knee 1 in. above head of fibula. Large fragment lying posterior to external condyle. (See *Fig.* 370)	—	Nil
25	5.5.17	High-explosive shell	Severe compound fracture of left patella with penetration of joint	—	Resection of patella. Irrigation of joint. Salt pack
26	9.5.17	High-explosive shell	Entrance wound internal to centre of left patella the size of a sixpence. Large high-explosive fragment lying deep in internal condyle. (See *Fig.* 371)	*B. perfringens*	Packing placed in track with B.I.P.P. No operative procedure
27	9.5.17	High-explosive shell	Through-and-through wound of left knee, with compound fracture of outer articular half of external condyle	—	Excision of track. B.I.P.P placed in joint. Suture of capsule. Wound closed
28	3.5.17	High-explosive shell	Minute wound to inner side of left patella. High-explosive fragment lying in joint	—	Removal of high-explosive fragment. Joint treated with 2 per cent formalin and glycerin. Capsule sutured. Wound closed
29	19.5.17	High-explosive shell	Wound to inner side of right knee. Fragment lying in infrapatellar pouch to outer side of joint	Effusion sterile	Joint opened widely. Foreign body removed. Saline douche. B.I.P.P. applied. Capsule sutured. Skin closure

CASES—*continued.*

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
Same day	18.4.17. Multiple incisions in calf. High-explosive fragment removed. Carrel-Dakin treatment continued. 4.5.17. Resection. 23.5.17. Amputation	Necrosis of the bared shaft of the femur was the ground for amputation; possibly a wider removal of the femur might have been successful	Stump healed	Amputation
Three days	Removal of high-explosive fragment through posterior incision. B.I.P.P., gr. 15, placed in joint. Capsule sutured. Original wound excised	Nil	31.5.17. Temperature normal. No effusion. Wound healed	28.8.17. Is walking. Some mobility. Still having massage. 12.9.17. "He has a good mobile knee-joint, but not perfect"
—	Splinting	—	9.5.17. Temperature normal. No effusion	Flexion to a right angle. Good functional limb. Is back with his regiment
Five days	8.5.17. Lateral incisions into joint, and eusol wash. B.I.P.P., gr. 15, placed in joint. 10.5.17. Resection of joint	3.6.17. Secondary abscess in suprapatellar pouch	6.7.17. Bony union. Wounds granulating	12.9.17. Is walking, but still uses sticks. 10.10.17. Is walking well without aid
Three days	Removal of foreign body. B.I.P.P., gr. 15, placed in joint. Suture of capsule. Wound closed	Nil	7.6.17. Wound healed. No effusion. Temperature normal	28.8.17. Mobile knee, but still on crutches
Same day	19.5.17. Carrel-Dakin treatment. Counter-incision at apex of Scarpa's triangle	—	17.6.17. Wounds granulating. Temperature normal	Stiff knee
Three days	High-explosive fragment removed. Cavity in condyle cleansed. B.I.P.P., gr. 15, applied. Suture of capsule and of wound	Lacerated wound of left deltoid and biceps; also wound of face	8.6.17. Wound healed. No effusion. Temperature normal	—
Same day	Nil	Superficial wounds of left chest and buttock	6.6.17. Wound healed. No effusion. Temperature normal	—
Two days	Nil	Nil	28.5.17. Wound healed. No effusion. Temperature normal	—
Same day	Splint and extension applied	Nil	14.6.17. Wound healed. No effusion. Temperature normal	Developed femoral thrombosis after first massage in England. 3.9.17. Still in bed

Continued on next page

PARTICULARS OF

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
30	25.5.17	High-explosive shell	High-explosive fragment traversed left patella, fracturing the external condyle and outer head of tibia	—	External wound excised. Latera meniscus removed. Damage bone chiselled away. Patell removed. Area treated wit B.I.P.P. Pack externally. Re mainder of wound closed
31	28.5.17	High-explosive fragment, 3in. × 5in.	Ligamentum patellæ and joint capsule torn. Fragment fell on the ground	—	Wound excised. Track treate with B.I.P.P. and sutured
32	2.6.17	Machine-gun bullet	Through-and-through wound of right knee-joint, traversing both condyles and causing a fissured fracture into the joint	—	Entrance wound excised dow to bone. Joint washed out an closed. Area treated wit B.I.P.P. Exit wound packe down to bone
33	3.6.17	High-explosive shell	High-explosive fragment the size of a pea lay in left suprapatellar pouch. Entrance wound above and outside left patella	Diphtheroid bacillus	Nil
34	28.2.17	High-explosive shell	Multiple wounds of left thigh, both buttocks, both legs, both knee-joints. All wounds small	Effusion sterile	Nil
35	13.12.16	High-explosive shell	Multiple minute penetrating wounds about left knee-joint	Streptococci	Splinting. This case was treate by aspiration and by injectio of iodoform and glycerin up t 26.12.16
36	4.2.17	High-explosive shell	Compound fracture of left internal condyle involving joint	—	Joint washed out with salin Comminuted bone remove Capsule sutured. Salt pac down to fracture
37	8.2.17	High-explosive shell	High-explosive fragment penetrated left knee-joint, fracturing patella and lying in head of tibia	—	Joint washed out with eus Capsule sutured after remov of foreign body. Salt pa down to tibial wound
38	10.2.17	High-explosive shell	Entrance wound to inner side of left knee-joint. Fragment lying postero-internally to internal condyle	—	Joint explored. Foreign bo not found. Eusol and eth wash out. Suture of capsul Wound closure
39	8.2.17	Bullet	Through-and-through wound of suprapatellar pouch, with compound fracture of right femur	Nil	Wounds enlarged
40	(?)	Shrapnel ball	Entrance wound 1 in. above centre of right patella. Shrapnel ball lying at level of joint centre under external lateral ligament	Nil	Splint applied

CASES—*continued.*

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
Nineteen hours	31.5.17. Plug removed. 16.6.17. Dead bone removed from head of tibia and condyle. 18.6.17. Amputation	Chronic osteomyelitis of shaft of femur, necessitating amputation	Stump healed	Amputation
Twenty-three hours	Splint and extension applied	Nil	12.6.17. Wound healed. Temperature normal. No effusion	Mobile joint. Wears a bandage, but walks very well
Three and a half hours	Repacked	Nil	25.6.17. No effusion. Pack still in outer portion of wound. Suture line healed elsewhere	—
Two days	High-explosive fragment removed. Joint washed out. B.I.P.P., gr. 15, applied. Capsule sutured. Skin closure	13.6.17. An abscess outside the joint was opened	29.6.17. Temperature normal. No effusion. Wound granulating	—
Four days	4.3.17, 5.3.17, and 8.3.17. Multiple incisions for gas gangrene. Both joints aspirated	*B. perfringens* infection of the flesh wounds	No effusion. All wounds granulating	Right thigh amputated in England. Still in hospital. No report as to reason for amputation
Thirteen days	26.12.16. Posterior and lateral drainage. Carrel-Dakin treatment. 19.1.17. Resection of joint	Nil	7.3.17. Wounds granulating. Temperature normal	10.10.17. Back at old employment. Walks well. Two inches of shortening
—	Thomas splint and extension applied	Nil	8.3.17. Wound granulating. No effusion. Temperature normal	—
Same day	Thomas splint and extension applied	Nil	All wounds healed	12.8.17. Fair mobility. Doing light duty with reserve battalion
Same day	Nil	Entrance and exit wounds posterior cervical region. Foreign body *in situ*	Wound healed. Temperature normal. No effusion	—
(?)	26.2.17. Wounds further enlarged. Carrel-Dakin treatment of joint	Prolonged sepsis	Wounds granulating. Bony union. No effusion	—
Three days	Shrapnel ball removed. Joint treated by Campbell's method of posterior drainage and with Carrel-Dakin solution	Nil	Wounds healed. No effusion. No temperature	12.7.17. Good result. Flexion to a right angle. Doing duty with reserve battalion

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PARTICULARS O

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
41	7.6.17	High-explosive shell	Large lacerated area of muscle laid open on inner side of right knee-joint. Wound of chest wall, and compound fracture of left clavicle	Strepto-cocci	The tear of the capsule was n observed at the casualty clea ing station. Large area tissue, 6 in. × 4 in., over inn side of joint was excised, a B.I.P.P. applied
42	7.6.17	Shrapnel ball	Entrance wound in centre of left popliteal space. Ball lodged in internal condyle	Effusion sterile	Nil
43	7.6.17	Shrapnel ball	Entrance wound outside and below left patella. Shrapnel ball lying to inner side of joint	Effusion sterile	Ball removed. Joint irrigate Capsule sutured. Entran wound excised
44	3.6.17	High-explosive shell	Many minute fragments in right knee-joint, right ankle-joint, and leg	Effusion sterile	Several fragments removed fro knee-joint, one from head tibia, and one from head fibula. Wounds left open
45	24.4.17	High-explosive shell	Compound fracture of right patella, with separation of fragments. Compound fracture of left tibia and fibula. Flesh wounds of left thigh	—	Suture of patella. Carrel-Dak treatment
46	8.6.17	High-explosive shell	Compound fracture of right patella, with penetration of a large high-explosive fragment. (See *Fig.* 372)	—	Foreign body removed. Joi washed out with eusol. Caps sutured. Pack down to pate
47	2.6.17	High-explosive shell	Through-and-through wound of right suprapatellar pouch	—	Wounds enlarged. Carrel-Dal treatment
48	6.6.17	Shrapnel ball	Entrance below and internal to right patella. Exit in region of adductor tubercle	Effusion sterile	Excision of wounds (?). notes
49	7.6.17	Shrapnel ball	Entrance wound below and to outer side of the right patella. Ball traversed joint and lay in vastus externus at a higher level	Effusion sterile	Nil
50	8.6.17	Rifle bullet	Entrance wound 2 in. above upper border of left patella in mid-line. Exit at a level 3 in. lower and slightly internal, in the popliteal space. *X* rays show nil	Effusion sterile	Nil
51	8.6.17	High-explosive shell	Entrance wound internal to centre of left patella. Large high-explosive fragment buried deeply in intercondylar notch. (See *Fig.* 373)	*B. perfringens*	Nil
52	14.6.17	High-explosive shell	Through-and-through wound to inner side of right knee, penetrating the capsule and causing wound of internal condyle outside joint	Effusion sterile	Wounds excised. Joint irrigat Capsule sutured. B.I.P.P. bony lesion
53	14.6.17	Rifle bullet	Through-and-through wound of left suprapatellar pouch	—	Thomas splint and extension

ASES—*continued.*

IME FROM ECEIPT OF VOUND TO PERATION	TREATMENT AT BASE	COMPLICATIONS	CONDITION ON EVACUATION	RESULT
ive days o opera- n at base)	12.6.17. Joint opened on either side of patella. Flavine irrigation. 15.6.17. Amputation of thigh	Duodenal ulcer. Hæmorrhage	—	19.6.17. Death
—	Splint and extension applied	Nil, except that foreign body is *in situ*	30.6.17. Temperature normal. No effusion. Ball *in situ*	—
en hours	Nil	Nil	28.6.17. Wounds healed. No effusion. Temperature normal	28.8.17. Some mobility. Still on massage, but walking well
)ne day	Carrel-Dakin treatment	Mild sepsis of all wounds	27.7.17. Wounds granulating. Normal temperature	12.12.17. Walking, but knee is stiff
our hours	Continuation of Carrel-Dakin treatment	...	18.6.17. Wounds granulating	3.9.17. Subsequently the patella necrosed. Knee stiff
ree hours	Packs re-applied	Nil	26.6.17. Wound granulating. No effusion. Temperature normal	—
even days ay out)	Continuation of Carrel-Dakin treatment	Nil	30.6.17. Wounds granulating. No effusion. Temperature normal	—
(?)	Splint and extension applied	Nil	26.6.17. No effusion. Temperature normal. Wounds healed	—
hree days	10.6.17. Shrapnel ball removed. Cavity excised and treated by B.I.P.P. Suture	Nil	20.6.17. Wound healed. No effusion. Temperature normal	28.8.17. Good mobile knee. Walks well
—	Splint and extension applied	Nil	26.6.17. No effusion. Temperature normal. Wounds dry	—
wo days	10.6.17. Resection of joint	—	31.7.17. Good bony union. Wound healed. Temperature normal	9.9.17. Walking with crutches
Twelve hours	Nil	Nil	1.7.17. No effusion. Wound healed. Temperature normal	—
—	Nil	Nil	26.6.17. No effusion. Temperature normal. Wounds healed	29.8.17. Good mobile knee-joint

Continued on next page.

PARTICULARS (

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
54	18.6.17	High-explosive shell	Entrance wound in left popliteal space $1\frac{1}{2}$ in. internal to centre. Fragment the size of a pea lying anteriorly over internal semilunar cartilage	*Staphylococcus albus*	Splint
55	13.6.17	High-explosive shell	Penetration of left knee-joint, with compound fracture of patella and both condyles. (See *Fig.* 374)	Streptococci	Removal of foreign body a portion of external cond Carrel-Dakin treatment
56	7.6.17	Rifle bullet	Entrance wound to outer side of right patella. Exit low in popliteal space. Fracture of outer head of tibia. (See *Fig.* 375)	Streptococci	Joint opened by anterior in sions and flushed with eu B.I.P.P. applied and caps sutured. Posterior wound larged
57	29.6.17	Revolver bullet	Entrance wound fracturing left patella and opening joint. The bullet lay below and outside the patella. Multiple fragments of lead penetrated the joint. (See *Fig.* 376)	—	Casualty clearing station writ " Wound front of knee exci and enlarged. Patella fou to be comminuted. Joint i gated with saline, ether inject wound sutured. Counter-in sion in popliteal space o round movable body found be sesamoid in biceps "
58	26.6.17	High-explosive shell	Entrance wound to outer side of left knee, traversing joint. Two small fragments the size of peas lay in the external condyle	—	Entire track excised down bone. Injured bone goug away, and foreign bodies moved. B.I.P.P. applied a joint capsule sutured
59	27.6.17	High-explosive shell	Wound over right patella. Compound comminuted fracture of the patella. Joint opened widely	—	Toilet and suture. B.I.P.P. us
60	1.7.17	High-explosive shell	Multiple minute wounds penetrating left knee-joint, right eye, legs, thighs, face, chest wall, and left testicle	—	Joint explored. None of t minute fragments found. Wou closed
61	9.7.17	High-explosive shell	Large fragment entered external aspect of right knee, traversed joint, and lodged deeply in outer head of tibia. (See *Fig.* 378)	Streptococci	Fragment removed. B.I.P applied, with pack into head tibia
62	5.7.17	High-explosive shell	Entrance wound to outer side of right knee-joint. Joint traversed. High explosive fragment lying in outer condyle under the cartilage	Nil	Fragment removed. Cav cleansed. B.I.P.P appli Capsule sutured and wou closed

ASES—*continued.*

...me from ...eceipt of ...ound to ...peration	Treatment at Base	Complications	Condition on Evacuation	Result
...ree days	Foreign body removed by anterior incision. B.I.P.P. placed in the minute cavity in the joint. Capsule sutured. Wound closed	Nil	3.7.17. Wound healed. No effusion. Temperature normal	27.8.17. Full movements of joint
...ne day	30.6.17. Amputation on account of general ill condition and extensive tracking of pus	—	Stump clean, but flaps not sutured	Amputation
...ight days ...lay out four)	1.7.17. Refused amputation, so Campbell's posterior operation performed. 4.7.17. Consented to amputation. Operation performed accordingly. 6.7.17. 650 c.c. of blood by direct transfusion. 11.7.17. Pyæmic abscess of left knee-joint. Joint opened and washed out. B.I.P.P., gr. 15, applied. 17.7.17. Pyæmia in left shoulder-joint. Similarly treated	Pyæmia in left knee- and shoulder-joints. Osteomyelitis of femur in amputation stump	—	20.7.17. Death
...ree days	2.7.17. Antero-external incision. Bullet removed. Large tear found in capsule. B.I.P.P., gr. 15, placed in joint. Capsule sutured. Minute leaden fragments not searched for	Nil	25.7.17. Wound healed. Temperature normal. No effusion	7.9.17. Mobile joint. Degree of flexion increasing daily
Twelve hours	Nil	Nil	26.7.17. Wound healed. Temperature normal. No effusion	—
...me day	Nil	Nil	27.7.17. Wound healed. No effusion. Temperature normal	—
...ree days	Splinting and extension. Enucleation of right eye. Evacuation of abscess in left tunica vaginalis	—	30.7.17. Wound healed. No effusion. Temperature normal	12.9.17. Mobility improving. Still under treatment
...en hours	13.7.17. Resection of joint	Abscess in suprapatellar pouch	4.10.17. Fibrous union. Femur has slid outwards on the tibia slightly (see *Fig.* 378). Wounds granulating	—
Eight hours	Extension and splinting	—	20.9.17. Wound healed. No effusion. Temperature normal	—

Continued on next page.

PARTICULARS

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
63	7.7.17	High-explosive shell	Superficial wounds of scalp, wrist, arms, and hands. Large fragment of high-explosive shell entered internal condyle of right knee, tearing the capsule; another fragment lay external to capsule of right knee. Compound fracture of toes of right foot. Multiple wounds about left knee-joint; several minute fragments in the joint. Compound fracture of toes of left foot	Effusion sterile in both knees. *B. perfringens* infection of wound outside capsule of right knee	High-explosive fragment moved from internal condyle right knee. B.I.P.P. appl after cleansing cavity. Pa placed *in situ*. Amputat of toes of both feet. Ot wounds cleansed
64	11.7.17	High-explosive shell	Compound fracture of right patella. High-explosive fragment tore capsule and lay in joint	Sterile effusion	Foreign body removed. Jo washed out and filled w ether; B.I.P.P. to pate Suture of capsule and clos of wound
65	1.3.17	High-explosive shell	Multiple minute fragments penetrating left knee-joint	—	Nil
66	13.7.17	Machine-gun bullet	Entrance wound above and to outer side of centre of patella. Exit through biceps just above its insertion. Was hit while kneeling. No evidence of a fracture. No x-ray photograph	—	Back splint
67	5.7.17	High-explosive shell	High-explosive shell wounds of back of neck. Wounds of right leg with fracture of fibula; wound of right knee with injury to external condyle (furrowed); probably a through-and-through wound	—	Foreign bodies removed fr neck and leg. None found knee-joint. Capsule sutu after eusol and ether wa out. B.I.P.P. applied outs capsule. Wound sutured
68	15.7.17	High-explosive shell	Wound over internal condyle of right knee-joint. Capsule opened. Two minute particles in condyle	—	Wound excised. B.I.P.P. plied. Knee-joint not thou to be penetrated
69	24.7.17	High-explosive shell	Minute perforations of right suprapatellar pouch	—	Joint washed out. B.I.P.P. plied. Capsule sutured. Wou excised
70	31.7.17	Shrapnel ball	Entrance wound below and outside right patella. Ball traversed joint and head of tibia, and lay under the skin below inner head of tibia	—	Nil
71	31.7.17	Rifle bullet	Through-and-through wound of right suprapatellar pouch	Effusion sterile	Back splint
72	31.7.17	Shrapnel balls	Entrance wound of right knee-joint on a level with upper margin of patella; ball lodged in external condyle; no evidence of joint penetration. Left knee: Three wounds of entrance clustered above and to inner side of patella; three balls lying above and external to patella outside joint; one traversed suprapatellar pouch, possibly two. Penetration of left tibia, ball lying below and in front of head of fibula	—	Nil

CASES—*continued.*

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
Thirteen hours	13.7.17. High-explosive fragment removed from right knee region, lying outside capsule. Wound to internal condyle enlarged. Carrel-Dakin treatment instituted to this wound	Severe nephritis	17.8.17. Urine 60 to 70 oz. No albumin. Some effusion remains in left knee-joint. Right knee, no effusion. Track to internal condyle remains open	—
Ten hours	Splint and extension applied	Nil	30.7.17. Temperature normal. Wound healed. No effusion	23.8.17. Good mobile joint. Complete flexion
—	Nil	Fragments *in situ*	24.3.17. Wounds dry. Tem. normal. No effusion	—
—	Thomas splint and extension applied	—	23.7.17. Slight effusion. Temperature normal	—
ame day	Nil	—	23.7.17. Temperature normal. No effusion	—
Sixteen hours	Splint and extension applied	Foreign bodies *in situ*	1.8.17. No effusion. Temperature normal. Fragments *in situ*	—
Twenty hours	Nil	—	3.8.17. Suture healed. No effusion. Temperature normal	—
ıree days	Removal of shrapnel ball	—	5.8.17. Sutures still in. Effusion diminished. Temperature normal	—
—	Thomas splint and extension applied	Nil	11.8.17. Effusion diminished. Temperature normal	—
ıree days	Five shrapnel balls removed. B.I.P.P. applied and wounds left open. Joint treated expectantly	—	18.8.17. Wounds granulating. Temperature normal. No effusion	—

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PARTICULARS OI

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
73	31.7.17	High-explosive shell	Missile traversed left suprapatellar pouch and entered the right leg below and behind the abductor tubercle, lodging in biceps tendon	—	Nil
74	31.7.17	High-explosive shell	Multiple high-explosive shell wounds about left knee-joint. One small fragment lies in joint	—	Joint explored after excision one wound. Nothing foun Capsule sutured. Wound close
75	5.8.17	Shrapnel ball	Compound fracture of right patella. Shrapnel ball lodged in joint	—	Removal of the ball and resectic of patella. Joint closed aft treatment with formalin ar glycerin. Skin suture
76	5.8.17	High-explosive shell	Small fragment penetrated left knee-joint just external to ligamentum patellæ	—	Removal of foreign body. Trea ment with B.I.P.P. Capsu sutured. Wound closed
77	31.7.17	High-explosive shell	High-explosive fragment lodged in patella. Joint opened	—	Block excision of track and fra ment. Joint washed out wi saline and closed. Wound le open
78	31.7.17	High-explosive shell	Compound comminuted fracture of both condyles of left femur	—	Resection of joint and suture operation wound
79	5.8.17	High-explosive shell	Wound outside and above right patella. Capsule torn. High-explosive fragment lodged in external condyle	*B. perfringens*	Casualty clearing station open joint to inner side of patella ar failed to find fragment. Joi washed out and treated wi formalin and glycerin. Capsu sutured. Entrance wound outside then explored. Forei body not found
80	28.7.17	High explosive shell	Penetrating wound into outer head of tibia, involving joint capsule	—	High-explosive fragment moved. Cavity treated w B.I.P.P. and pack applied
81	23.7.17	High-explosive shell	Entrance in popliteal space. Fragment injured articular branch of popliteal artery and entered joint, lying behind inner head of tibia	—	Clot evacuated. Artery li tured. Foreign body not fou Wound treated with B.I.P and left open
82	31.7.17	High explosive shell	Entry over anterior aspect of left external condyle, exit at centre of popliteal space (complete fracture of condyle). (See *Fig.* 379)	Streptococci	Back splint

ASES—*continued.*

TIME FROM RECEIPT OF WOUND TO OPERATION	TREATMENT AT BASE	COMPLICATIONS	CONDITION ON EVACUATION	RESULT
—	Fragment removed from right biceps tendon. Wound left open	—	12.8.17. Temperature normal. Wounds granulating	—
Within twenty-our hours	Nil	—	20.8.17. No effusion. Temperature normal	—
Three hours	Nil	—	22.8.17. Temperature normal. Wound healed. No effusion	—
ght hours	Nil	—	14.8.17. No effusion. Temperature normal. Stitches still in	—
our hours	Nil	Nil	20.8.17. Temperature normal. Wound granulating	—
Thirty hours	Posterior ham-splint applied. Alinement adjusted	—	29.8.17. Has some bony union. Slight lateral displacement of shaft of femur outwards	—
our days o operation at base	9.8.17. Removal of large fragment from external condyle. Capsule found to be torn the whole length of the suprapatellar pouch externally. Stitches from casualty clearing station wound removed, and long incision made in vastus externus. Bony cavity cleansed. B.I.P.P. applied. Wound left open. 14.8.17. Carrel-Dakin treatment. 3.9.17. Secondary suture, leaving track to bony cavity. 21.9.17. Resection of joint (see *Fig.* 377)	Mixed infection following *B. perfringens*	10.10.17. Fibrous union in good position	—
ourteen hours	7.8.17. Repacked	—	10.8.17. No effusion. Temperature normal. Pack *in situ*	—
Twelve hours	Nil	—	8.8.17. No effusion. Temperature normal. High-explosive fragment *in situ*	—
ine days	9.8.17. Removal of condyle for drainage 11.8.17. Resection of joint, necessitating a high section of shaft of femur	—	10.10.17. Evacuated in good position, with bony union	—

Continued on next page.

PARTICULARS O

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
83	15.8.17	Rifle bullet	Through-and-through wound with compound fracture of left patella (fissured)	Effusion sterile	Joint opened and washed wi saline, followed by suture capsule and skin closure
84	17.8.17	High-explosive shell	Multiple small wounds about right knee. One fragment in external head of tibia. One fragment in head of fibula. Also wounds of right thigh, right hand, right leg, and right foot	—	Removal of high-explosive fra ment from thigh. Woun about knee joint not operat on
85	23.8.17	High-explosive shell	Through-and-through wound of left suprapatellar pouch. Also entry wound to inner side of joint anteriorly. Small fragment lying behind shaft of femur. Fragment in right astragalus	—	Wounds excised and treated wi B.I.P.P. ? suture of capsu Skin cleansed
86	3.8.17	High-explosive shell	Entrance wound over inner head of right tibia. High-explosive fragment lodged in bone. Fissured fracture into joint. Multiple wounds elsewhere	Sterile effusion	Fragment removed. Brillian green pack and tempora suture
87	22.8.17	High-explosive shell	High-explosive fragment lodged in right tibia. Capsule penetrated. Compound fracture of superior maxilla	—	Wounds excised. Joint wash out. Capsule sutured. Fra ments not removed (lyi posteriorly in the bone: wou anterior)
88	23.8.17	High-explosive shell	Fragment of high-explosive shell, 7 × 2 mm., penetrated ligamentum patellæ and joint capsule, and lodged in inner head of tibia	—	Fragment removed. Ether jected. Brilliant-green pack the bone, and temporary sutu
89	17.8.17	Rifle bullet	Entrance wound above and behind head of left fibula. Exit above and anteriorly to inner head of tibia	Effusion sterile	Nil
90	23.8.17	High-explosive shell	Through-and-through wound of right lateral pouch	—	Joint washed out. Capsule s tured. Wounds excised a closed
91	21.8.17	High-explosive shell	Entrance wound to inner side of right knee-joint at level of joint. Fragment the size of a pea traversed the joint and lodged deep in the internal condyle	Sterile effusion	Back splint
92	21.8.17	High-explosive shell	Fragment traversed external head of left tibia and lay in joint	—	Removal of fragment. Jo washed out, and B.I.P.P. pa applied to cavity in tibia
93	24.8.17	High-explosive shell	X-rays show metallic dust in joint (?)	—	Casualty clearing station wash out joint and noted fissure junction of internal condy cartilage with bone. Caps sutured, external wound trea with B.I.P.P. Closed

ASES—*continued.*

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
Three days (lay out)	Thomas splint and extension applied	Nil	30.8.17. Wound healed. No effusion. Temperature normal	—
Ten days	Amputation of terminal phalanx right ring finger. High-explosive fragment removed from head of right tibia. External condyle is exposed. Wound left open. B.I.P.P. pack	—	1.10.17. Wounds granulating. Temperature normal. No effusion	—
—	30.8.17. High-explosive fragment removed from right ankle-joint. B.I.P.P. and suture	—	3.9.17. No effusion. Temperature normal	10.10.17. Walking fairly well
Seventeen hours	Brilliant-green pack changed for B.I.P.P. pack. Thomas splint and extension applied	—	14.9.17. No effusion. Temperature normal	—
Nineteen hours	Toilet of mouth and suture of lip	—	7.9.17. No effusion. Temperature normal	—
Eleven hours	Thomas splint and extension applied. Pack removed. Dry dressing	—	4.9.17. Temperature normal. No effusion. Wound granulating	—
—	—	Irregular pyrexia (P.U.O.)	2.10.17. Knee off splint. Movements good. Temperature now normal	—
Twelve hours	Thomas splint and extension	—	4.9.17. Temperature normal. No effusion. Stitches still in	—
—	Thomas splint and extension	—	4.9.17. Temperature normal. Effusion diminished	—
Twelve hours	Pack removed	Nil	4.9.17. Suture line healed. Wound in tibia granulated. Temperature normal	—
Twelve hours	Thomas splint and extension applied	—	4.9.17. No effusion. Temperature normal. Stitches *in situ*	10.10.17. Walking, but knee still stiff. Under treatment

Continued on next page

PARTICULARS O

Case No.	Date of Wound	Missile	Nature of Injury	Organisms Found	Treatment at Casualty Clearing Station
94	24.8.17	High-explosive shell	Through-and-through wound of right knee-joint. Entrance wound internal to inferior margin of patella. Exit behind head of fibula	—	Aspiration of blood and synovi fluid
95	27.8.17	High-explosive shell	Wound over internal condyle of right knee-joint. Capsule torn by fragment, which lodged in internal condyle, outside the capsule	*Staphylococcus aureus*	Removal of fragment. Capsu sutured. Wound closed, wi drain down to fracture
96	1.9.17	High-explosive shell	Fragment entered left knee-joint, and lay loose in region of internal condyle, tearing ligamentum patellæ as it entered. High-explosive fragment lodged in calcaneo-astragalar articulation, fracturing the astragalus. Entrance and exit wounds of left buttock	—	Fragment removed. Lavage joint with eusol. Suture capsule, and repair of ligame tum patellæ. Wound closed
97	30.8.17	High-explosive shell	Multiple wounds about right knee-joint, penetrating capsule. No bony lesion. No foreign body retained	—	Excision of wounds. Lavage joint. Suture of capsul B.I.P.P. Wound left open
98	5.9.17	High-explosive shell	Large laceration of vastus externus, tearing the capsule in the region of the right suprapatellar pouch	—	Excision of wound. Joint irrig tion with Dakin's solutio Capsule sutured. B.I.P.P. a pack into wound. Tempora suture over pack
99	9.9.17	High-explosive shell	Lacerated wound of left thigh, with tear in capsule of left suprapatellar pouch. Many fragments of bone (from a comrade) implanted	—	Excision of wound. Removal alien bone. Joint lavage wi Dakin's solution. Capsule s tured. B.I.P.P. Closure wound
100	5.9.17	High-explosive shell	Penetration of right knee-joint, with comminution of patella, and with a fragment lodging in intercondylar notch. Compound fracture of right tibia, lower third	—	Resection of patella. Remov of foreign body. Toilet of bor cavity between the condyl B.I.P.P. applied and capsu sutured. Skin closed as far possible. B.I.P.P. applied right tibia

ASES—*continued.*

Time from Receipt of Wound to Operation	Treatment at Base	Complications	Condition on Evacuation	Result
wo days	Thomas splint and extension applied	Nil	6.9.17. No effusion. Temperature normal	—
wo days	Thomas splint and extension. Drain removed. 13.9.17. Resection of joint	—	11.10.17. Fibrous union in good position	—
Fourteen hours	6.9.17. Large high-explosive fragment removed from left ankle-joint	—	1.10.17. Temperature normal. No effusion	—
Twenty- hours	Splint and extension	Compound fracture of left patella	27.9.17. Temperature normal. No effusion in the joint	—
Twelve hours	Stitches removed. Pack changed	Division of right ulnar artery. Superficial wounds of left leg and forehead	22.9.17. No effusion. Temperature normal	—
Within twenty- ur hours	Splint and extension	Wounds of right thigh and left forearm	21.9.17. No effusion. Temperature normal	—
ighteen hours	Splint and extension	—	2.10.17. Wound granulating. Temperature normal	—

A CASE OF FASCIAL GRAFTING FOR THE REPAIR OF TRAUMATIC STRICTURE OF THE URETHRA.

BY STAFF SURGEON R. J. WILLAN, R.N.V.R.

ON July 28, 1911, Albert L., age 32, fractured his pelvis through being crushed between a moving tub and the wall while working down a coal mine. He bled from the urethra and had retention of urine. He was removed at once to a hospital, where his bladder was immediately opened, both perineally and suprapubically, in order to relieve the acute retention. He states that during the next four months he had several operations, "as the passage could not be kept open." Apparently these 'operations' consisted of passing dilating bougies under a general anæsthetic.

Despite frequent attempts, no dilating instrument had been passed through the stricture for the fourteen months previous to the patient coming under my care. For the last six months of this period he had increasing difficulty in getting his urine away; he had to strain very hard at micturition, to such a degree that he had incontinence of fæces; moreover he was endeavouring to pass urine every half-hour night and day. The stream was getting smaller, until it had become a forceless dribble, and several times he had had temporary retention of urine; but relief had always been gained by the local application of hot flannels.

On Jan. 7, 1913, he was admitted to the Royal Victoria Infirmary, Newcastle-upon-Tyne, with acute retention of urine. Before he left his home the doctor had informed him that the only possible relief he could look forward to was a permanent suprapubic fistula. In appearance he was thin and anæmic. There were healed scars in both the perineal and suprapubic areas. The urethroscope demonstrated a stricture just behind the compressor urethræ muscle; the opening of the stricture could not be defined. A rectal examination demonstrated a hard mass of cicatricial tissue at the normal situation of the prostate; the gland itself not being recognizable with the examining finger owing to the inflammatory tissue. The *x* rays showed an old united fracture of both pubic bones.

Emergency Operation.—To relieve the acute retention, an endeavour was made to insinuate the fine gum-elastic 'guide' of a urethrotome through the stricture preliminary to dividing it by internal urethrotomy; this was not successful. The patient was therefore placed in the lithotomy position, and the urethra was opened in the perineum on a Wheelhouse staff. Despite a prolonged search, the opening of the stricture could not be recognized. I then opened the bladder suprapubically, and the area of the stricture was examined by means of a metal sound passed by retrograde catheterization into the prostatic urethra. At the same time a finger was inserted into the rectum.

It was ascertained that the ends of the torn urethra were separated by half an inch of scar tissue; also that the prostatic end of the canal was deflected, and fixed in dense cicatricial tissue in a position well to the right of the middle line and downwards towards the free margin of the triangular ligament (*Figs.* 380, 381, 382). The bladder was drained suprapubically by a tube; the urine was highly offensive, owing to a purulent cystitis.

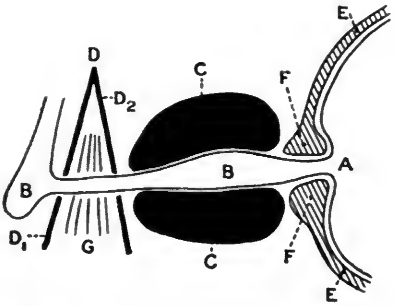

FIG. 380.—Showing the normal relations of the parts.

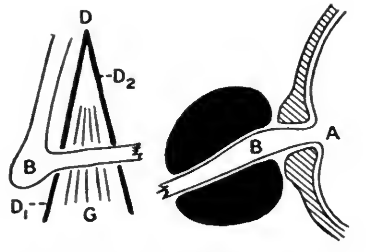

FIG. 382.—Showing the downward displacement of the proximal fragment

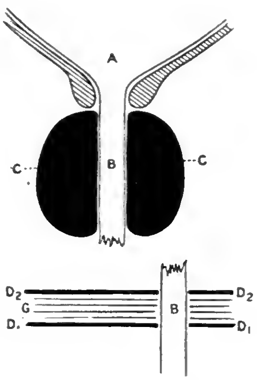

FIG. 381.—Showing the lateral separation of the torn ends.

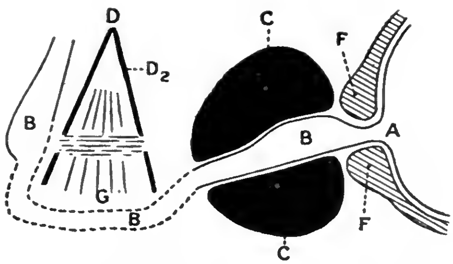

FIG. 383.—Showing the fascial graft (in dotted outline) uniting the penile and prostatic portions of the urethra. The membranous portion has been destroyed, and is replaced by fibrous tissue.

FIGS. 380–383.—DIAGRAMS OF THE PROSTATIC AND MEMBRANOUS URETHRA, ETC., ILLUSTRATING THE NORMAL RELATIONS OF THE PARTS AND THE CONDITIONS IN THE PRESENT CASE.

A, Bladder. B, Urethra. C, Prostate gland. D, Triangular ligament. D_1 Superficial layer of ligament; D_2, Deep layer. E, Bladder-wall muscle. F, Internal sphincter. G, Compressor urethræ.

First Plastic Operation.—Some time before, I had the advantage of watching Professor Morison do a successful plastic operation upon the penile urethra of a lad; the patient had a stricture about two inches behind the external meatus, and a piece of tensor fasciæ femoris was used for the plastic.

On Jan. 23, I performed a plastic operation upon my patient in the following manner. Placing him in the lithotomy posture, the separated ends of the torn urethra were first defined. Owing to the inaccessibility of the anterior torn end, where it emerged at the *posterior layer* of the triangular

ligament, the urethra was completely divided transversely immediately in front of the *superficial layer* of this ligament. The epithelial lining of the membranous portion of the urethra was completely destroyed by swabbing it with acidum carbolicum liquefactum. The cicatricial tissue in front of the proximal end of the torn urethra was dissected away. My work now was to fill in the gap between the two ends of the urethra, a gap larger than ever owing to my destruction of the membranous portion. In other words, I had to provide a new length measuring $1\frac{1}{4}$ inches, which, moreover, must be left with a permanent lining of epithelium if a cure was to be effected. In filling up the gap, the new part of the urethra had either to tunnel the triangular ligament or be carried round its free margin. The latter alternative was chosen, because it was the easiest.

I obtained a length (about $1\frac{1}{2}$ inches) of the patient's left internal saphenous vein at its upper part, together with an oblong (2 inches by 1 inch) from his tensor fasciæ femoris; both of these were handled as little as possible, and were kept immersed in hot saline solution until they were actually required. This fascia (with its glistening muscle surface towards the lumen) was first sutured into position with interrupted catgut sutures; these were placed close to the cut margins of the urethra in front and behind, also laterally; no attempt was made to approximate the lateral margins of the fascia, that is, to complete the 'floor.' The vein was slit up as it lay in the saline solution. Unfortunately the lumen was of small calibre; but its extremities were sutured to the cut ends of the urethra by interrupted catgut sutures, while the sides of the cut vessel were sutured to the portion of tensor fasciæ femoris which enveloped it. The new portion of the urethra therefore consisted of a piece of vein, around the outer surface of which a fascial flap was wrapped, and the 'floor' remained quite open. To prevent any adhesion of the surfaces, and to provide a splint, a rolled-up piece of indiarubber tissue was laid along the *whole* length of the urethra. The suprapubic drainage tube was retained.

At the end of seven days the rubber tissue drain was removed. Three days later I passed a No. 15 (English gauge) metal bougie. When the point of the instrument was passing the site of the plastic operation, I felt something tear, although the instrument passed onwards into the bladder quite easily. There is no doubt that the tearing, hardly perceptible though the sensation was, was sufficient to dislodge completely the anterior detachment of the graft. The bougie was passed again a few days later, but the bladder was reached with difficulty. A few days after this the bladder could not be reached at all, even under a general anæsthetic.

Second Plastic Operation, Feb. 5.—As I attributed the failure of the first plastic operation largely to the small calibre of the vein employed, I resolved to use a fascial graft only at the next attempt. Having obtained an oblong of tensor fasciæ femoris, similar in size and shape to the one used at the previous operation, this was fixed into the gap by interrupted catgut sutures to either end of the urethra; the graft was also sutured laterally to the surrounding tissues, although the 'floor' lay quite open. As in the previous operation, the glistening medial surface of the graft was turned towards the lumen of the urethra. It lay in the place occupied before by the length of

saphenous vein, that is, it was sutured directly to the ends of the urethra. The relation of the new portion of the canal to the base of the triangular ligament is shown in ***Fig.*** 383.

The posterior end of the urethra was slit along the floor into the prostate gland. A short length of rubber tubing was laid in the prostatic urethra, and brought out through the perineal wound behind the level of the urethral graft; this tube had its lumen occluded with a ligature, and the inner end did *not* enter the bladder. To the middle of the upper surface of this rubber tube was sutured a piece of indiarubber tissue drain; this was brought out through the external meatus. The posterior part of the urethra, therefore, was occupied by a rubber tube, while the rest of the canal was occupied by rubber tissue. A small piece of iodoform gauze was placed at the areas of suture both in front and behind. The services of the suprapubic drainage tube were still employed.

The perineal tube and the tissue drain were left undisturbed for ten days; each day the perineum was carefully irrigated with saline solution to wash away any pus which had accumulated, and at the end of the time mentioned the perineal drains were removed. At the end of fourteen days a No. 16 (English gauge) metal bougie was easily passed.

The suprapubic drainage tube was kept in until April 5, by which time it was quite certain that the bougie could be passed with perfect ease. By the time that the patient left hospital, nine days later, the suprapubic sinus was soundly healed, and he was passing a full-sized stream during micturition.

After-History.—For a week or two after the suprapubic wound had healed, the patient had a slight incontinence of urine. I saw him on June 26,—i.e., twenty weeks after operation—when he had full control of micturition, and I passed a No. 14 bougie with ease.

On Aug. 7, 1914, he came to see me by request, when he looked well and fat. He stated that he had some urgency of micturition, and that if he could not arrange to pass his water immediately the desire was felt, his urine came away. However, there was no incontinence of urine, night or day. He had to get up once during the night to micturate, while during the day he could carry on for three hours. The stream was a single, full-sized one. A No. 16 (English) catheter was passed without any difficulty. Wishing to know the appearance of the graft, I examined him with the urethroscope. It showed, 5 inches from the external meatus, the lumen rather narrower than the portion in front; while instead of the straw colour of a normal part of the urethra, the new portion was white in colour like scar tissue; unlike scar tissue, however, this surface had a 'sheen' on it, due to a covering of epithelium.

I again saw the patient in February, 1916—that is, over three years after the operation. He was then in good health, and a No. 16 (English) bougie was passed without obstruction. He still had some urgency of micturition.

The urgency is a sequel to his long-standing cystitis. The infection was probably self-induced, for he had been using a dilating bougie upon himself ever since the time of the original accident. When I last saw him he was continuing this practice. I tried to persuade him to give up the habit, as he was really cured, but he could not forget his previous sufferings when unable

to micturate. He stated that it gave him great mental comfort to be able to satisfy himself periodically that a large bougie passed easily.

In a letter from him dated Oct. 14, 1917, patient informs me that he is in good health, but still passes the bougie from time to time.

Remarks.—The first plastic operation failed primarily owing to the vein being of too small a size; secondarily, to my passing a bougie too soon afterwards, for the point of the bougie encountered the vein, which acted as an obstacle and tore away the anterior attachments as mentioned.

A difficulty to overcome was to prevent the surface of the tensor fasciæ femoris from adhering, and the soft, pliable, rubber tissue drain was used as being less likely than gauze to destroy the fascial graft.

The fascial graft probably only acts as a scaffolding for the urethral epithelium to grow along. I consider that this has certainly happened, for the urethroscope shows that there is a sheen on the walls of the lumen at this new portion of the urethra, which can *only* be due to epithelium. The ability to pass a large-sized bougie so easily is confirmatory evidence; for if the walls of the 'gap' were lined with cicatricial tissue instead of epithelium, it would very quickly close up and become an impassable stricture. Professor Morison suggests that the epithelium referred to may possibly originate from the surface of the graft. I therefore asked Professor Stuart McDonald if he would examine sections of tensor fasciæ femoris with a view to ascertaining if there are any endothelial cells upon the medial surface of this fascia. He has very kindly done so; sections cut from two cases were examined, and he informs me that he cannot see any trace of endothelial cells. He suggests that a number of cases should be examined, though he would still expect the search for endothelium to be negative.

The patient is of course entirely dependent upon the bladder sphincter (at the internal meatus) for continence of urine, because his compressor urethræ muscle cannot now play any part in this function. He was warned of the risk of incontinence of urine before the plastic operation was embarked upon, but he promptly expressed his willingness to risk anything rather than continue his previous miserable existence of constant endeavouring to micturate; nor could he tolerate the alternative of having a permanent suprapubic fistula. Fortunately, with the exception of some urgency, he has full control.

A NEW OPERATION FOR THE SUBSTITUTION OF A THUMB.

By Brevet-Major J. L. JOYCE, R.A.M.C. (T.)

An operation has been devised to substitute a ring finger of the opposite hand for a thumb lost as a result of injury or disease. The well-known method of employing a pedunculated flap is used in this operation, but the idea of substituting a finger for a lost thumb of the opposite hand is believed to be a new and useful advance in surgery.

The patient for whom this operation was devised, and on whom it was afterwards practised, is an electrical engineer who lost the whole of his right

Fig. 384.—The right hand before operation.

Fig. 385.—*X*-ray photograph of the right hand before operation.

thumb, including its metacarpal bone, as the result of a gunshot wound received in action on the Somme in July, 1916 (*Figs.* 384, 385). The operation is described under the following headings :—

1. Preparation of the bed for the reception of the new metacarpal bone, and exposure of the proximal end of the divided tendons of the old thumb.

2. Dislocation of the ring finger of the opposite hand at the metacarpo-phalangeal joint, involving division of the soft tissues at the base of the radial

side of the proximal phalanx, division of the extensor and flexor tendons, and the preservation of a nutritive flap on the ulnar side of the finger.

3. Fixation of the new metacarpal bone (proximal phalanx of ring finger) in its bed, union of tendons and nerve, suture of incisions, and fixation of the hands in apposition.

4. Division of nutritive flap—two months later than 1, 2, and 3.

1. An incision is made along the radial border of the hand, beginning at a point which corresponds with the horizontal level of the centre of the web between the index finger and the thumb of the sound hand, and rather nearer the dorsum than the palm. When the wrist is reached, the incision is carried along the radial border of the forearm for a distance of $1\frac{1}{2}$ to 2 inches. The incision on the side of the hand is deepened sufficiently to accommodate the new metacarpal bone, care being taken not to cut across muscle fibres. In the patient on whom the operation was performed, a plane of fibrous tissue was found apparently filling up the space left by removal of the metacarpal bone, and in this the bed was made. The articular surface of the trapezium is exposed. The skin and superficial and deep fascia on either side of the incision along the radial border of the wrist are reflected, the tendons of the extensores secundi internodii pollicis, primi internodii pollicis, ossis metacarpi pollicis, flexor longus pollicis, and flexor carpi radialis are defined, and one of the dorsal cutaneous branches of the radial nerves is found and divided.

2. An inverted V-shaped incision is made on the radial side of the ring finger, the apex of the incision being placed midway between the dorsal and palmar aspects of the finger at the level of the proximal inter-phalangeal joint. The triangular piece of skin marked out by the incision is then reflected upwards. The limbs of the incision are carried obliquely backwards and forwards on to the dorsum and palm of the hand, and are deepened in order to expose the extensor and flexor tendons. These are divided at the extremity of the incisions, and the proximal ends prevented from retracting by suturing them to the periosteum and soft tissues covering the metacarpal bone. The soft tissues are now divided at the base of the proximal phalanx on its radial side down to the periosteum. The digital vessels on this side of the finger are tied, and the distal end of the collateral branch of the median nerve is sought for and identified. The extensor and flexor tendons are dissected up in a distal direction, exposing the base of the proximal phalanx, and a hole is drilled through the base of the bone and threaded with a stout catgut suture. The finger is now dislocated from the metacarpal bone by cutting through the ligaments of the metacarpo-phalangeal joint. The soft tissues on the ulnar side of the proximal phalanx are raised for a short distance from the periosteum, working from the deep aspect, taking care not to injure the digital vessels.

The triangular flap of skin is now turned down to cover over the head of the metacarpal bone, and the incisions on the dorsum and palm of the hand are sutured with fine catgut stitches. The proximal end of the extensor tendon is pulled over to the palmar aspect of the hand, and the ring finger is then ready for grafting into its new position.

3. The two hands are apposed in a manner which is sufficiently indicated in the accompanying photographs (*Figs.* 386, 387). This stage of the operation is now completed as follows :—

a. The flexor tendons of the finger are joined to the long flexor of the thumb, if this has been found, or to the flexor carpi radialis if more convenient.

b. The proximal phalanx is anchored in its position by stitching the catgut suture threaded through its base to the scar tissue covering the articular surface of the trapezium.

Fig. 386.—The two hands apposed in plaster-of-Paris.

Fig. 387.—The two hands grown together after removal of the plaster.

c. The extensor ossis metacarpi pollicis is stitched to the periosteum at the base of the proximal phalanx (new metacarpal bone).

d. The tendons of the extensores secundi and primi internodii pollicis are united and joined to the extensor tendon of the finger (new thumb).

e. The radial cutaneous nerve exposed in the first stage of the operation is sutured to the collateral branch of the median nerve of the ring finger.

f. The skin incisions are sutured. The incision on the radial border of the wrist is sutured in a distal direction to cover the base of the new metacarpal bone and the tendon unions. The dorsal and palmar edges of the incision on the radial border of the hand are sutured to the dorsal and palmar edges of the skin bordering the triangular raw area on the radial border of the ring finger (new thumb). Fine interrupted catgut sutures are used throughout for the skin stitches.

FIGS. 388, 389.—The right hand after the operation was completed.

FIG. 390.—X-ray photograph of the right hand after the operation was completed.

The hands are then fixed in the apposed position by plaster-of-Paris, which is left undisturbed for four weeks, and is then removed.

4. The final stage in the operation consists in dividing the nutritive flap, separation of the hands, ligature of the proximal ends of the ulnar digital vessels of the finger which has been removed, and closing the raw areas which remain. *Figs.* 388, 389, 390 show the hand after completion of the operation.

Fig. 391.

The time for completing the operation depends on the establishment of a sufficient collateral circulation between the vessels of the new thumb and its hand. This can be easily tested by compressing the blood from all the fingers (including the late ring finger) and the hand of the member which has provided the new thumb, and stopping the arterial blood-supply. All the fingers will then remain cold and blanched, with the exception of the late ring finger, which will retain its warmth and colour if an efficient new circulation has been established.

In the case of the patient on whom this operation was performed, the first three stages were carried out on Aug. 11, 1917. The plaster was removed on Sept. 14. The hands were separated on Oct. 13.

In performing the operation, every step was carried out as described, with two exceptions:—

a. The flexor tendons of the ring finger were not united to the flexor longus pollicis or the flexor carpi radialis, but were left unattached in the bed of the thenar muscles.

Fig. 392.

b. No nerve union was made between the digital nerves of the ring finger and the cutaneous nerves of the opposite hand.

These steps were omitted as it seemed desirable that too much should not be attempted at once. The first omission matters, for while the patient

has now acquired active voluntary movements of the extensors, he has no power of flexing the two terminal phalanges of his thumb.

The omission of the nerve union is thought to be of little importance, as the patient already has a considerable return of protopathic sensation on the ulnar side of his new thumb (radial border of the late ring finger).

The accompanying photographs (*Figs.* 391, 392, 393, 394) are a sufficient commentary on the usefulness of the patient's new thumb, and it is enough to add that he now feels himself able to follow his profession, and can write a legible letter with his right hand, holding his pen in the usual manner.

Fig. 393.

Fig. 394.

Figs. 391–394 illustrate the usefulness of the new thumb.

The whole of this patient's right thumb has been replaced by the ring finger of the left hand, and it is considered that by suitable modifications in the details of the operation any less part of a thumb can be similarly replaced by substituting for it a part of a finger of the opposite hand.

My thanks are due to Mr. A. Rhodes, who not only gave me his assistance at the operation, but has prepared the photographs which illustrate this paper, and to my Commanding Officer, Brevet-Colonel W. J. Maurice, for his advice and encouragement, and for his permission to publish the case.

SHORT NOTES OF RARE OR OBSCURE CASES.

CASE OF TRAUMATIC ANEURYSM OF THE RADIAL ARTERY.

By Temporary Surgeon C. P. G. WAKELY, R.N.

Traumatic aneurysm of the radial artery is not very common, no doubt owing to the fact that the vessel is often completely cut across, or that, in shell wounds, a portion of the vessel is often blown away together with the surrounding muscles. Mr. Rutherford Morison[1] describes a case in which he excised the sac of the aneurysm, and Sir George Makins,[2] in his article

Fig. 395.—Antero-posterior view.

Fig. 396.—Lateral view.

Skiagrams of lower part of forearm, showing the piece of steel lying about two inches above the wrist.

"Vascular Lesions in War," reports one case of traumatic aneurysm of the radial artery in a series of 111 cases of traumatic and arterio-venous aneurysm. Sir George Makins considers that traumatic aneurysms of the radial and ulnar arteries are rare, "on account of their small size, and the frequency with which they suffer complete division."

The case I am about to describe occurred in a discharged Belgian soldier (H. S.), age 26. He was working in a blacksmith's shop in Camberwell in

March, 1915, when a small piece of hot steel struck his left forearm on its outer aspect about $2\frac{1}{2}$ inches above the wrist; it caused him some pain for the moment, but he soon forgot all about it. About three weeks afterwards he attended King's College Hospital because a small pulsating swelling had appeared above the wrist on the antero-external surface of the forearm. This was thought to be an aneurysm of the radial artery. The patient was x-rayed, and a small foreign body was seen lying close to the inner surface of the radius about 2 inches from the lower end of the bone (*Figs.* 395, 396). The patient was kept under observation for a week, the swelling increasing during that time to the size of a pigeon's egg.

An operation was performed on April 5. A vertical incision was made over the tumour, and the sac excised, hæmorrhage being easily controlled by

FIG. 397.—Aneurysmal sac opened to show laminated clot.

compressing the brachial artery against the tendon of the biceps in the antecubital fossa. The proximal and distal portions of the artery were ligatured. The piece of steel was found to be sticking into the side of the aneurysmal sac. The wound healed rapidly, and the collateral circulation was perfect. *Fig.* 397 shows the dissected sac.

Radical treatment was indicated in this case, because the aneurysm was rapidly increasing in size and any traumatism might have caused its rupture, either externally or into the subcutaneous tissue of the forearm. In either of these conditions operation would have been needed at once, would have been much more difficult, and suppuration might have taken place.

Excision of the aneurysmal sac is recommended by Regnault and Bourrat-Laconture[3] in cases of aneurysm of the small arteries of the extremities. They report a case of aneurysm of the superficial palmar arch treated by ligature of the artery at each end of the sac.

REFERENCES.

[1] Brit. Jour. Surg, 1914, i, 724. [2] *Ibid.*, 1916, iii, 391. [3] *Rev. de Chir.*, 1913, 337.

A CASE OF PARTIAL SEPARATION OF THE CALCANEAL EPIPHYSIS.

By C. HAMILTON WHITEFORD, Plymouth.

A boy, age 14, while paddling in the sea, slipped, and brought the bare heel of the left foot into hard contact with a rock.

7th Day.—Seen for the first time. The posterior and plantar surfaces of the heel were tender. There was slight lateral swelling, with no discoloration. The *x* rays showed a partial separation of the calcaneal epiphysis (*Fig.* 398). The heel was bandaged, with the foot in plantar flexion. Weight-bearing on the foot was prohibited, and gentle massage was applied daily to the parts surrounding the tender area.

Fig. 398.—Skiagram showing partial separation of the epiphysis of the os calcis.

29th Day.—The tenderness was unaltered, the patient having made repeated attempts to bear weight on the foot. The limb was fixed in a poroplastic case extending from the toes to the middle of the thigh. The case held the foot in plantar flexion, with forty degrees of flexion at the knee.

47th Day.—Tenderness had nearly disappeared. Gentle walking was permitted, the boot having a raised heel.

68th Day.—An ordinary boot was worn.

15th Week after the injury.—Walking was normal. There was no tenderness. Dorsiflexion and plantar flexion were perfect. Viewed from the sole, there was slight lateral thickening in comparison with the uninjured side.

Comments.—Traumatic separation of the calcaneal epiphysis appears to be rare. Little or no information on the subject is given in the text-books. Normally the epiphysis unites with the body of the bone soon after puberty. It will be of interest to note what effect the injury may produce on the development of the heel.

A CASE OF GUNSHOT WOUND OF THE LIVER, WHERE THE MISSILE, ENTERING THE CIRCULATION THROUGH THE HEPATIC VEIN, WAS FOUND LODGED IN THE RIGHT VENTRICLE OF THE HEART.

By Captain J. E. McCARTNEY, R.A.M.C.,
and Captain HAMILTON DRUMMOND, R.A.M.C.

Several instances have recently been described of 'wandering' shrapnel balls and shell fragments within the vascular system; the present case deals with a wandering fragment of shell.

The missile, a triangular piece of shell about one inch in length, entered the thorax between the seventh and eighth ribs on the right side, in the

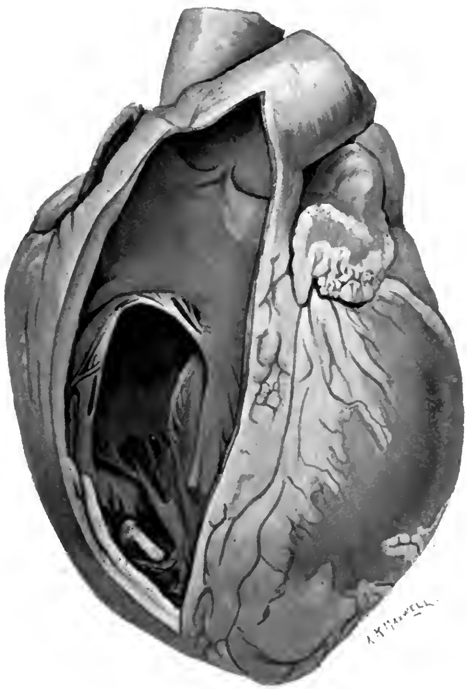

Fig. 399.—Right side of heart laid open to show missile lying embedded in the ventricle.

mid-axillary line. It then opened the right pleural cavity without touching the lung, pierced the diaphragm, and entered the liver. The fragment traversed the right lobe, and passed into a large branch of the right hepatic vein, in this way gaining access to the inferior vena cava. The missile was subsequently found at autopsy lying between the columnæ carneæ of the right

ventricle of the heart, its apex being surrounded by firm white clot which was not of recent origin (*Figs.* 399 and 400).

The patient had, in addition, other serious wounds, and survived his injuries for thirty-six hours. The presence of the missile in the heart was not suspected during life.

At the autopsy, the liver showed a large lacerated wound of the right lobe, but no exit wound was visible. When the track of the missile was fol-

FIG. 400.—X-ray photograph of heart taken from behind, so that missile appears on right side of photograph.

lowed up, it became evident how the shell fragment had gained access to the circulation. The wall of the hepatic vein showed a long ragged tear, about two inches in length, where the missile had entered obliquely (*Fig.* 401).

From the fact that the shell fragment was very rough and irregular, and that there was neither damage to the intima nor adherent clot in the inferior vena cava, it seemed probable that the missile, on entering the vena cava, was very soon carried up in the blood stream to the right auricle, from whence it would naturally drop into the ventricle.

The fatal issue in this case was probably due to a combination of hæmorrhage from the hepatic wound, and shock. It could not be attributed to the presence of the missile in the heart.

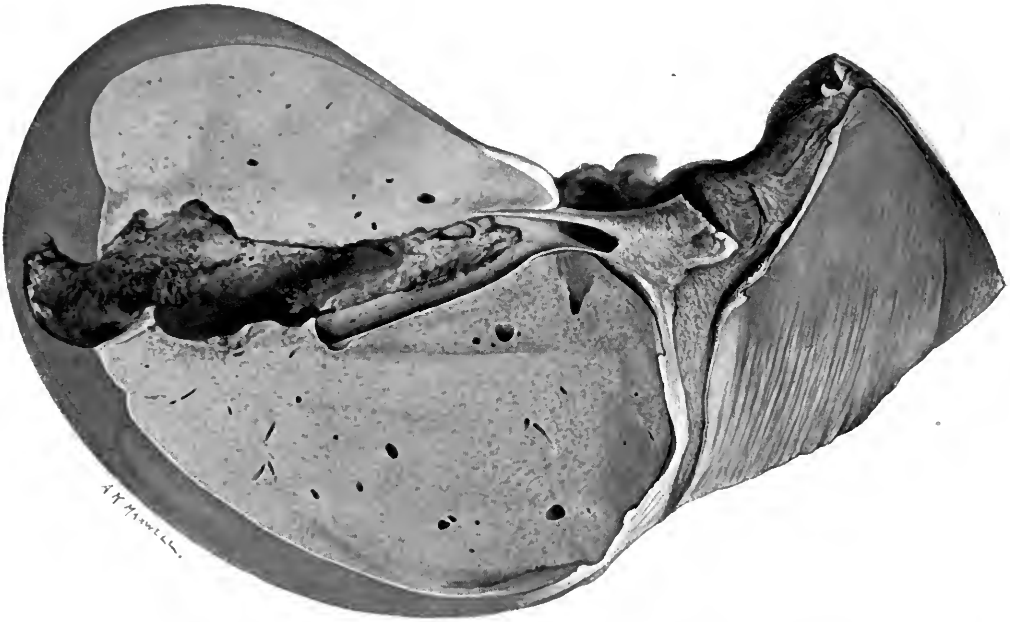

FIG. 401.—Section of liver showing the ragged wound of entry of missile into right hepatic vein.

We are indebted to the Medical Research Committee for permission to reproduce the two drawings by Sergeant A. K. Maxwell, R.A.M.C.

AN UNUSUAL CASE OF RENAL CALCULUS.

BY F. C. PYBUS, NEWCASTLE-ON-TYNE.

Although calculi, wherever situated, often tend to assume the shape of the cavity in which they are contained, it is rare for them to form a complete cast of the interior of their cavity. The renal calculus here described formed a perfect cast of the interior of the pelvis and calices of the kidney and the upper portion of the ureter.

Private R. A. C., age 36, was admitted to the 1st Northern General Hospital on Aug. 31, 1916, with pains in the left loin and back. He showed two small phosphatic calculi which he had passed recently, and stated that he had passed similar ones for years. It was found he had a temperature of 101°, that the urine was alkaline and contained pus, and that there was a large tender swelling in the left loin. A diagnosis was made of perinephritic abscess, due probably to calculous pyonephrosis.

X-ray examination showed a shadow in the region of the left kidney,

corresponding to the caliees and pelvis, and to the upper part of the ureter (*Fig.* 402). Major Arnison reported that this latter region was occupied by a large calculus, or was filled with dense pus.

On Sept. 2, an oblique incision was made in the left loin, and about one pint of stinking pus evacuated. The cavity was drained by a rubber tube. The pus contained a pure culture of the *Streptococcus longus*. A few days later a second *x*-ray examination revealed the shadow in the same situation.

On Sept. 27, the wound having closed down to a small sinus with very little discharge, a second operation was undertaken. The original wound was enlarged, and the kidney found, containing a large stone in its pelvis. The kidney was separated, and drawn up to the margin of the wound. The stone seemed too large to be removed by opening the pelvis, so the kidney was incised along its convex border. The renal tissue was not greatly thinned; the stone was therefore disengaged from the calices, and withdrawn without difficulty. Two small isolated fragments, seen in the

Fig. 402.—Skiagram of left loin, showing shadow of renal calculus.

Fig. 403.—Photograph of stone after removal. (× ¾.)

skiagram, were removed from adjoining calices. A probe was passed down the ureter, which was patent. A tube was inserted into the pelvis of the kidney through the cortex, and the remainder of the wound in the kidney was closed with catgut sutures. The incision in the loin was then closed, a small drain being left in the perirenal space.

On Nov. 8 the patient was discharged to an auxiliary hospital, the wound being healed. He was much improved in general condition, the urine containing only a trace of pus. On two occasions since the operation he passed small calculi per urethram. No further calculi could be detected in either kidney or bladder.

Fig. 403 shows the stone, three-quarters of the actual scale, which weighs just over $1\frac{1}{2}$ ounces, and, even when dried, has still a trace of smell. It appears to be composed of phosphates, and forms a complete cast of the pelvis and calices and the upper $1\frac{1}{4}$ inches of the ureter.

HÆMATEMESIS AND MELÆNA CAUSED BY A PIECE OF METAL FROM THE ŒSOPHAGUS PERFORATING THE AORTA.

By NORMAN H. BEAL, London, Canada.

On May 8, 1917, the writer was called in consultation by Dr. C. W. Crawford to see a woman, age 60, suffering from severe shock following hæmatemesis. The history and progress of the case were briefly as follows:—

The patient, a trained nurse, was found during the previous afternoon lying on the floor in a pool of blood. Twice during the next eighteen hours she vomited a quantity of bright red blood, which showed no characters to indicate that it had come from the lungs. The patient was placed under morphia, all nourishment by mouth was interdicted, and rectal salines with 5 per cent glucose were administered. The source of the hæmorrhage was thought to be probably from the stomach or duodenum. On the morning of May 9 the patient seemed somewhat improved; she had not vomited for twenty hours, but had passed two large stools of bloody material. She now complained of severe precordial pain, radiating down the left arm, and a constant desire to vomit. No history of previous trouble could be elicited, and fearing that in the absence of a definite history laparotomy would fail to discover the source of the hæmorrhage, the writer advised against operation. In this Dr. H. A. McCallum, who was called in consultation, agreed. Efforts were made to procure a donor for transfusion in case of further hæmorrhage. At 6.0 p.m. another large movement of blood was passed per bowel, accompanied by hæmatemesis. The patient became pale, and showed the clinical signs of a large loss of blood. As a suitable donor had not been obtained, an intravenous saline was given: but the patient failed to respond, and died at 7.0 p.m., fifty-two hours after the first hæmatemesis.

Post-mortem Examination.—Permission for an autopsy was granted, which was performed by Dr. F. W. Luney, of the Institute of Public Health. The following is a brief summary of the findings:—

Stomach.—On opening the stomach, three or four large blood-clots were removed. The mucosa is not thickened at any point, and there are no evidences of ulceration.

Duodenum.—The duodenum contains a mass of blood-clot, but there is no thickening of the walls or evidence of ulceration.

As there are no definite pathological findings in the abdomen, it is necessary to open the chest. On removal of the breast-plate, a large mass, about the size of a fist, is seen in the mediastinum just above the base of the heart. This is quite firm in consistency, and appears to involve the various structures of this region.

The heart, aorta, and œsophagus, including the mediastinal mass, are removed intact. The heart, aorta, and œsophagus are laid open. On the inner and anterior wall of the œsophagus, at a point opposite the arch of the aorta, there is found an irregular small opening a quarter of an inch in diameter. This opening is found to be filled with blood-clot, which becomes continuous with a large clot that is present in the œsophagus. This opening leads into the cellular tissue of the mediastinum between the œsophagus and arch of the aorta. Examination of the arch of the aorta reveals a small irregular opening an eighth of an inch in diameter, situated $1\frac{1}{2}$ inches to the left of the great vessels that go to the head and neck. This opening also is found to lead into the same cellular tissue as the opening in the œsophagus. The involved cellular tissue, which constitutes a mass between the œsophagus and arch of the aorta 2 by $2\frac{1}{2}$ inches in diameter, is infiltrated with blood-clot. Further examination reveals, lying in this space, a flattened piece of metal, $1\frac{1}{4}$ inches in length, and sharpened at both ends.

Post-mortem Diagnosis. — Hæmorrhage from injury produced to the walls of the œsophagus and aortic arch by a piece of metal.

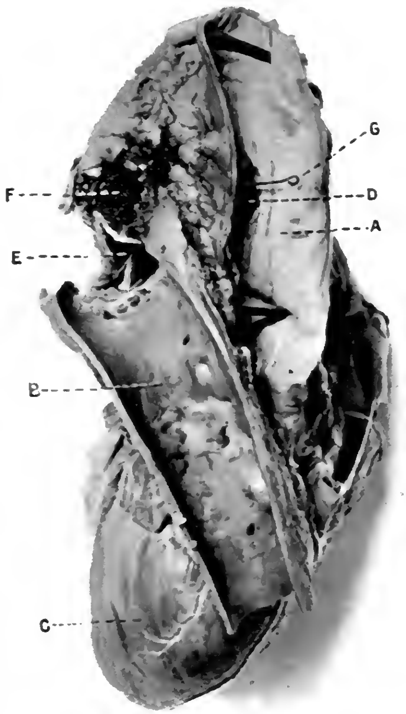

Fig. 404.—Specimen showing the wounded œsophagus and aorta. A, Œsophagus. B, Aorta. C, Left ventricle. D, Opening through œsophageal wall. E, Opening in aortic wall. F, Space in mediastinal tissue filled with clot in which the piece of metal was found. G, Probe indicating course traversed by the piece of metal. ($\times \frac{1}{3}$.)

Piece of metal causing the wounds. (*Actual size.*)

The accompanying figures (*Fig.* 404) illustrate the autopsy findings and the cause of the clinical picture. The perforation of the aorta allowed blood to pass into the œsophagus; this trickled into the stomach, and after collecting, either passed into the intestine, giving rise to melæna, or was vomited.

A CASE OF TWO ANEURYSMS RESULTING FROM PENETRATION BY A SMALL SHELL FRAGMENT, ONE OF THE FIRST PART OF THE RIGHT SUBCLAVIAN, THE OTHER OF THE AORTA.

By Lieutenant-Colonel GILBERT BARLING, R.A.M.C.

Patient, age 33, was admitted to No. 1 Australian General Hospital, April 11, 1917, with a diffuse supraclavicular swelling on the right side, and with a small wound two inches above the middle of the right clavicle. The skin over the swelling was somewhat reddened and tumid, pitting slightly on pressure. A thrill could be felt all over the area, and the murmur was conducted more plainly towards the angle of the jaw than towards the axilla. Slight difficulty in swallowing existed; there was a little dyspnœa from time to time; the right pupil was contracted; and there was some hoarseness which suggested interference with one of the vocal cords, but the condition was not ascertained by laryngoscopic examination.

On April 15 the general swelling had diminished considerably, leaving a well-defined tumour about the size of a tangerine orange beneath and external to the lower part of the right sternomastoid. The thrill remained as before, and the murmur had in some degree the buzzing character usually associated with arterio-venous communications.

Radiography showed a foreign body at about the level of the second left costal cartilage and an inch to an inch and a quarter from the middle line; it was observed to move with the heart-beat, but no localization as to depth was carried out. Physical signs indicated fluid in the right pleura to the level of about the fifth rib posteriorly, and there was some displacement of the apex beat outwards.

On April 26, the notes say, "The size of the tumour has undergone no further change, but the skin over it is reddened and œdematous, and there is a little purulent discharge from the entrance wound. The temperature is 100·6° this morning. The radial and temporal pulses on the right side are smaller than on the left." In view of the inflamed condition over the aneurysm, it was thought unsafe to transmit the patient to England. Operation was therefore determined upon, and was carried out on April 28, with the assistance of Colonel Pilcher and Lieutenant-Colonel Quick.

On two previous occasions[1] I had exposed the innominate artery by an angle incision, the vertical limb along the anterior border of the sternomastoid, the horizontal along the inner portion of the clavicle; in these two cases the division of the artery was so high that the access attained was sufficient without removal of any part of the manubrium. The same incision was now adopted; but the division in the innominate was lower than in my previous experience, so by means of Hey's saw and gouge forceps part of the upper portion of the sternum was removed. The common carotid was exposed, and followed down into the innominate. Here, as when the innominate was exposed, the utmost difficulty was experienced in separating the vessel from its accompanying vein. By much expenditure of time this was eventually accomplished

safely. The sheath of the innominate was cleared from the vessel, the aneurysm needle was passed round the artery ready to receive the ligature, and all difficulties seemed to be surmounted, when there was a terrific gush of blood coming from below the level of the aneurysm needle. This was withdrawn, and the hæmorrhage controlled with the fingers. Attempts with forceps to close the source of the bleeding were followed by further hæmorrhage, absolutely flooding the wound, and the finger passed into a cavity, the nature of which was uncertain, whether superior vena cava, an auricle, or part of the aneurysmal sac. A small dry wound-swab was therefore packed firmly over the area whence the bleeding came, other swabs were used to fill the wound cavity, and the patient was returned to bed in fair condition.

Examination showed that pulsation in the subclavian aneurysm had ceased, and the right radial pulse was absent. At the moment it appeared that the manipulations had disturbed clot, which had plugged the wound in the artery; but possibly the change in the aneurysm and radial pulse was due to the firm pressure of the plugging on the origin of the subclavian.

On the second day some of the swabs were removed, others on the following days, and it was intended to attempt to complete the operation on the seventh day after the first failure. On the fourth day the patient was evidently losing ground; his breathing was more distressed; and on the fifth day 59 ounces of sterile blood-stained fluid were withdrawn from the right pleura. There was no real amendment, however, and death occurred on the sixth day, without return of hæmorrhage.

At the autopsy, the wound, mediastinum, pleuræ, and pericardium appeared to be uninfected. The heart, the great vessels, the subclavian aneurysm, and the first rib were removed in a mass. A radiograph showed the foreign body *in situ*, and it was eventually identified in the wall of the pulmonary artery just where the latter leaves the right ventricle.

Dissection showed that the external aneurysm was due to a wound of the first part of the subclavian artery and vein. The sac of the aneurysm was filled with firm laminated clot, and it is doubtful if there was any current through it at the time of death. A second aneurysm was found arising posteriorly from the arch of the aorta just where the first and second portions join; this sac was also filled with firm laminated clot, and it is clear that there was scarcely any current through the sac.

The missile, in its passage downwards and inwards from its point of entry, wounded the first part of the subclavian, passed across the arch of the aorta—this vessel showing wounds of entry and exit—and then lodged in the root of the pulmonary artery without penetrating to the interior of that vessel.

As the innominate vein and superior vena cava were intact, I can only conclude that in passing the aneurysm needle round the innominate, the root of that vessel was somewhat raised, and tore the edge of the second aneurysmal sac, and that from this source the hæmorrhage occurred.

REFERENCES.

[1] *Lancet*, 1905, Sept. 16; *Ibid.*, 1907, Nov. 16.

REVIEWS AND NOTICES OF BOOKS.

Malingering: or, The Simulation of Disease. By A. Bassett Jones, M.B. Lond., and Llewelyn J. Llewellyn, M.B. Lond.; with a chapter on Malingering in Relation to Eye Diseases by W. M. Beaumont. Large 8vo. Pp. 708, 5 plates. 1917. London: William Heinemann. 25s. net.

A most careful and exhaustive treatise upon the subject by the well-known authors of the treatise on fibrositis. It well deserves a place in the library of every medical man who is engaged in Workmen's Compensation practice. After introductory chapters dealing with the history, legal aspects, psychology, and diagnosis of malingering, the subject is considered in relation to diseases of the nervous system, internal diseases, accidental injuries, infections, and hernia, and it concludes with a section dealing with measures for the restriction of malingering. From a surgical point of view the articles on sprained back and allied conditions, and those on the injuries of the joints, are the most valuable. The whole work is marked by wealth of detail, a high degree of critical judgement, and scholarly finish, and it will prove a most valuable work of reference.

Emergency Surgery. By John W. Sluss, A.M., M.D., F.A.C.S., Associate Professor of Surgery, Indiana University School of Medicine. Fourth edition. Pp. 827, with 685 illustrations. 1917. London: William Heinemann. 17s. 6d. net.

The author tells us, in the preface to the first edition, that " this is a Surgery for the general practitioner; written not to instruct his leisure hour, but in the hope some time to serve as a guide out of uncertainty in a time of stress."

The work is a little difficult to criticize from the point of view of the general practitioner in this country, to whom it might have been made more valuable by elaborating the technique of operations he is likely to be called upon to treat by himself, and omitting that of others with which it is hardly likely that he will have to deal personally. In America, the land of vast distances, it is no doubt not only possible but probable that the general practitioner may be called upon to undertake any or every form of emergency surgery; but in this country, specialist help is always so near at hand that much of the material in the book will be quite wasted upon the general practitioner. The attempt to cover such a wide field has necessarily made the details of the minor surgical methods rather meagre, so that the book cannot vie on the one hand with such a volume as Lejars' *Chirurgie d'Urgence*, or, on the other hand, with the many excellent manuals of minor surgery that are to be found in this country. As an example of what is perhaps unlikely to be of use to the general practitioner, we may instance the elaborate directions for exposure and repair of individual nerves. Surely, the most the general practitioner is called upon to do is to re-unite nerves divided in a wound; the rest is a matter for a skilled surgical specialist. Similarly, bone-plating and the operative treatment of fracture of the patella are not matters that fall commonly within the province of the general practitioner.

Among points that are not quite in accord with modern practice may be noted the passage of drainage tubes across the knee-joint beneath the patella (p. 458), and the drainage of an empyema in a child without removal of a portion of rib.

There is an extensive section dealing with the surgery of gunshot wounds. This can hardly be deemed a matter for the general practitioner, and would have been better omitted. There are not enough definite details to make it valuable to the army surgeon, and it is altogether too voluminous for the rare gunshot injuries of civil life.

Nerve Wounds: Symptomatology of Peripheral Nerve Lesions caused by War Wounds. By J. Tinel, late Chef de Clinique at La Salpêtrière, with Preface by Professor Dejerine; translated by Fred. Rothwell; revised and edited by Cecil A. Joll. Pp. xii + 317, with 323 illustrations. London: Baillière, Tindal & Cox. 15s. net.

This work represents the outcome of the examination by both clinical and laboratory methods of a number of military cases. It is a publication only made possible by the co-operative work of a group of clinicians.

It deals chiefly with the details of 639 cases, and the French text of which it is the translation appeared only a little more than a year after the outbreak of the war. The very careful details given and illustrated of the different symptoms, paralytic, functional, and contractional, form a more precise picture of the various lesions than has ever before been published. The happy association of anatomical description with clinical illustration makes the work very convincing. The first section deals with general principles, including the histology of divided and regenerating nerves, and the general principles of diagnosis. The second and third parts describe the various lesions of the special nerves of the upper and lower limb. Of particular value is the distinction of the different groups of symptoms associated with various degrees of nerve interruption: these being complete interruption, compression, irritation or neuritis, and the neuralgic type.

From a surgical point of view, the most serious criticism we have to make is that the section devoted to treatment is compressed into about seven pages. It is a matter of urgent importance that an authoritative statement should be made as to the essentials in operative technique, and that this should be founded not merely on personal opinion, but upon the actual results observed at long periods after operation. According to the present authors, spontaneous recovery takes place in over sixty per cent of all cases, and therefore surgical intervention is not called for unless, at a period of several months after injury, there is no evidence of regeneration in the peripheral segment. Clear indication is given that direct end-to-end suture after excision of neuromata is the ideal to be aimed at by operation. The use of a sensory nerve as a graft is considered to be justified, but no cases are quoted to sustain this opinion. The use of flaps of living or dead tissue to surround the joined nerve is condemned. The numerous illustrations are clear, and add a great value to the best book on the subject which we possess at present.

Massage, its Principles and Practice. By James B. Mennell, M.A., M.D., Medical Officer Physico-therapeutic Department, St. Thomas's Hospital and London Military Orthopædic Hospitals. With an Introduction by Sir Robert Jones, Military Inspector of Orthopædics. Pp. xvi + 352, with 135 illustrations. 1917. London: J. & A. Churchill. 8s. 6d. net.

Dr. Mennell is an enthusiast, but a very sane enthusiast, and the present work greatly gains from this fact. It is not intended as a text-book for teaching massage, but rather as a presentation of the rôle of massage in the treatment of disease, and a discussion of its rationale.

The whole principle of successful orthopædic treatment is now recognized to be a close co-operation between the different methods, surgical, physico-therapeutical, and mechanical. It is, however, given to but few to be able quite intelligently to prescribe and carry out all these different forms of treatment. The surgeon must be dependent upon experts in massage and in electricity for the carrying out of these particular methods; but he must know sufficient both of principles and details to be the master and not the servant of the experts. The author has never lost sight of the teaching of the French surgeon, Lucas-Championnière, which was to the effect that the great value of massage is its reflex or nervous influence as a soothing agent, and that movement, natural and free, painless and voluntary, is the end and object of all massage treatment.

We admit that we are wholly converted to these views, and we most heartily hope that Dr. Mennell will convince all those who have to practise massage for

military patients. That massage is only a means to an end, and that this end, namely, voluntary movement, should be borne in mind from the very outset, is most important. But the other point—which is still more often overlooked, and which we should imagine is not accepted by many of the teachers and practitioners of massage—that massage should be primarily sedative and not stimulant, is equally important.

The book is concerned for the greater part in considering the massage treatment of injured limbs, but it contains also a consideration of its relation to nervous, circulatory, and digestive disorders.

The chapters relating to physical exercises deal almost entirely with a simple type of pulley machine, whereby all ordinary exercises can be carried out by the patient with a very compact and simple gymnastic outfit. But we think that however admirable this system of resisted movements may be, it does not fulfil all the functions which other systems such as Zander's perform. We quite realize that the author disapproves of these systems, but we think the book would have been of greater value if he had taken the trouble to discuss the theory, possibilities, and limitations of the various pendulum machines.

SHORT NOTES ON BOOKS.

Ligations and Amputations. By PROF. A. BROCA, translated by ERNEST WARD, F.R.C.S. Pp. 282. 510 illustrations. 1916. Bristol: John Wright & Sons Ltd. 8s. 6d. net. This book was favourably reviewed on the appearance of the original in French. It represents the classical teaching of Farabeuf, many of the illustrations being from this author's work. It is undoubtedly a most valuable book at the present moment because of its clearness, precision, and brevity.

A Handbook of Surgical Operations for the use of Students. By K. K. CHATTERJI. Pp. 229, plates 26, many in colours. 1916. Calcutta: Butterworth & Co. (India) Ltd. 7s. d6. net. A short and concise account of the ordinary operations performed on the dead subject, illustrated by numerous diagrammatic figures.

Acute Appendicitis. By C. HAMILTON WHITEFORD. Pp. 72. 1917. London: Harrison & Sons. 4s. net. A small book representing the result of the author's experience for over twenty-five years; his general remarks are so much in consonance with ordinary teaching that it is difficult to select any special points for notice.

JOHN ARDERNE.

1307–1380 (?).

JOHN ARDERNE is the first English surgeon of whom we have any detailed knowledge at present. He lived so early in the history of English surgery that he shows traces of the barren Saxon period when charms and wort cunning were prevalent, intermingled with the more fertile scientific methods derived from the schools of Salernum and Montpellier—methods which rendered possible the work of Lanfrank in Italy, of de Mondeville in Paris, and of Gui de Chauliac at Avignon. Arderne lived through the fourteenth century, and was essentially a general surgeon practising amongst all classes, first in the wars, then at Newark, and last of all, as an old man, in London. He was held in high esteem by his contemporaries, who admitted him to the Guild of Surgeons in London; and his teaching was so greatly appreciated by his successors, that numerous manuscripts of his writings still exist, both in Latin and in English translations.

Born in 1307, he was certainly writing as late as 1376, and perhaps for some years afterwards. He thus lived through the reign of Edward III, and being attached to John of Gaunt, he knew personally many of the heroes of the Hundred Years' War, men whose names are household words, for they live for ever in the pages of Jean le Bel and of Froissart. At a time when chivalry reached its highest development, Arderne lived with the most chivalrous. He seems to have visited Flanders, Algeçiras, and Guienne, and gives a few facts about his experiences in each place. He settled at Newark on Trent in 1349, perhaps because the ravages of the Black Death caused a temporary cessation of hostilities in France and compelled the military surgeons to seek a more peaceful livelihood. He practised at Newark until 1370, when he moved to London and was admitted into the Fellowship of Surgeons, a small guild distinct from the Fellowship of Barbers. The existing writings of Arderne are dated after his settlement in London, and are a series of tracts, or monographs as they would now be called, dealing with subjects of medical and surgical interest. It is clear from these articles that fistula resulting from spear and arrow wounds interested him, but he had no knowledge of gunshot injuries. The knights and gentlemen wore heavy armour, spent many hours in the saddle in all weathers, and were much constipated. They often suffered therefore from ischiorectal abscess followed by fistula in ano. Arderne boldly invented and used the operation of incision for fistula, and was so far in advance of his time that it fell into disuse after his death, and was not revived for nearly five hundred years. His patients ate and drank to excess, so he wrote a treatise on gout, and another on the diet of those with disease of the kidney. Seabies then, as now, was the scourge of camps, and he gives many directions for its cure. Gonorrhœa, or 'brenning,' was frequent, but of syphilis there is no hint. Hysteria or 'strangling of the matrice' he knew well and treated drastically.

He had learnt the great secrets of success in surgery: fearlessness as regards bleeding; cleanliness; infrequent dressing of wounds. These points are easy for us to grasp, but were most difficult for mediæval surgeons, who had no means of arresting hæmorrhage, and who had been taught for ages that wounds could only heal properly if they suppurated and so discharged their venom. In addition to his skill as a surgeon, Arderne was endowed with a sound common sense which enabled him to recognize the limits of his art, and when a case was incurable he did not hesitate to express his opinion, even if he lost his patient by so doing. Arderne recognizes several clearly defined grades of medical practitioner. There was the 'lady,' who gave simple advice and treatment; the apothecary, who sold drugs and plasters; the leech, sometimes skilful, more often foolish, who treated the patient before he brought him to the master surgeon—such an one as John Arderne himself; lastly, the physician, with whom the master surgeon often consulted, and seemingly on more equal terms than was the case several generations later.

Arderne lays down two cardinal rules for wound treatment. The spelling is modernized, the sentiments are his own: "To a leech be this a rule, that corrosive powder be never removed in a wound or an ulcer until it comes out of its own accord. Also there is another rule in which I have seen err in my time almost all men not practical but fools: that is to say, of the frequent dressing of wounds or ulcers. Such dressing speedeth not the cure but preventeth it. And when such idiots be openly known and not reproved, they vex themselves and their patients by their ignorance. He is a leech in name but not in discretion who uncunningly dresses a sore twice in a day. Galen sayeth the tree plant that is often changed shall not recover, and Hippocrates sayeth the wound becometh less healthy which is often re-dressed. Wounds therefore show such men to be idiots who are diligent and busy when it would profit more to both parties to rest than to labour in vain. They say the weather is hot, or the wound runneth or stinketh strongly, and therefore it is better to dress it often. This is untrue and followeth not, for though they say that the wound runneth strongly, and that the oftener it is dressed the better—that is to say twice or thrice in a day—it is not so, for such treatment preventeth the coming out of the matter, and the wound or botch is made worse, as is shown by experience. Let a leech be content with one dressing a day, and when he seeth a wound or an ulcer well cast out its discharge and the swelling for to vanish away and the aching for to cease and the member to come again to its first habit and colour, health is at the door if the patient be well governed, i.e., if he sleep well o' nights. Often times in many cases I was not wont to re-dress a wound but from the third day unto the third day, and I sped well and cured many difficult cases which had been forsaken by other men."

Arderne's operation for fistula is a modification of the method recommended, but apparently not used, by Albucasis (d. 1013), who taught that complete fistula was incurable, and that all operations and application of ointments were but labour in vain. Arderne recommended that a clean incision should be made through the fistula instead of fretting it through with a ligature tied tightly, as was done by all his predecessors, contemporaries, and successors. For this purpose he placed the patient in the

JOHN ARDERNE OPERATING FOR FISTULA IN ANO

lithotomy position, and passed a probe through the fistula until it was felt in the rectum. The eye of the probe was threaded with a ligature of four strands, which was drawn along the fistula as the probe was pulled out of the rectum, until one end hung out of the anus, the other from the external opening of the fistula. The two ends were knotted together, and were tightened by means of a peg fixed into the widest part of a gorget, in the same way that a violin peg tightens the string passing round it. The ligature was used partly to control the bleeding and partly to maintain a correct line whilst the fistula was divided. The gorget was now pushed well into the fistula, and a grooved director with a curved end was passed along it until the end projected into the rectum. A shield with a depression in its centre was then passed through the anus until the grooved director engaged in the depressed notch. The shield prevented the surgeon cutting down on his own finger, and at the same time protected the opposite wall of the rectum in case the patient struggled or made any sudden movement at the moment the fistula was divided. A scalpel was passed along the groove in the director, and the fistula was cleanly divided along its whole length by drawing the knife, the director, and the shield out of the rectum with a single movement, the ligature coming away at the same time. "Then it is to labour to stanch the blood. First put a sponge, wet in a little warm water and well wrung out, into the place of the cutting, and hold it there for it to receive the blood, and let it abide there a good while. When thou trowest the sponge to be full of blood, remove it, and if there be need, put again another sponge or the same ordained in the foresaid manner. And when thou hast done thus, have the patient raised warily, and make him sit hard in a convenient place upon the aforesaid sponge, and doubt not but that it shall be well stanched. Afterwards, when you deem it due time, be the patient put in a proper place and the sponge removed, and whether the blood be stanched or not, sprinkle it with a powder and apply clean and small stupes or well-teased cotton with linen clouts put on above. Let him be girded with a linen girdle, and afterward have a list of woollen cloth bound behind to the girdle, and let it descend atwixt his buttocks upon the clouts covering the perineum and be it fastened to the girdle upon the belly" [a T-bandage]. The cure was aided by daily enemata of oil injected through a wooden clyster pipe.

"For the cure of fistula in ano, when it is curable, ask of a worthi man and great an hundred marks or forty pound,* with robes and fees of a hundred shillings a year so long as he lives. Of lesser men forty pounds or forty marks ask he without fees. And take he not less than an hundred shillings, for never in all my life took I less than an hundred shillings for cure of that sickness.

"And if the patients or their friends or servants ask by how much time he hopeth to heal it, evermore let the leech state the double that he expecteth, that is if the leech hope to heal the patient in twenty weeks—that is the common course of curing—add he so many over, for it is better that the time

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* Forty pounds in 1367 purchased an annual rent charge of sixty shillings. The value of money was probably ten to fifteen times greater than it is at the present time.

be lengthened than the cure. For prolongation of the cure giveth cause of despairing to the patients when trust in the leech is most hope of recovery. And if the patient consider or wonder or ask why that he put him so long a time of curing when he healed him in half the time, answer he that it was because the patient was strong-hearted and suffered well sharp things, and that he was of good complexion and had able flesh to heal, and feign he other causes pleasing to the patient, for patients of such words are proud and delighted."

Arderne records his cases briefly, and yet so clearly that there is no difficulty in making a diagnosis. The following, for instance, is a case of traumatic tetanus with secondary hæmorrhage: "A gardener while that he wrought in the vines cut his own hand with an hook upon a Friday after the feast of St. Thomas of Canterbury in the summer, so that the thumb was altogether departed from the hand save only in the juncture that was joined to the hand, and he might bend backward the thumb to his arm, and there streamed out thereof much blood. And so touching the cure; the thumb was first reduced into its first order and sewed, and the blood was restrained with the red powder of Lanfrank and with the hairs of a hare, and it was not removed until the third day; and on the third day when it was removed there appeared no blood. Then was there put thereto those medicines that engender blood, every day once re-dressing the wound, and so it began to purge itself and to gather matter. And in the fourth night after, the blood brake out about midnight to the weight of two pounds. And when the blood was restrained the wound was dressed again from day to day as it was at first. Also in the eleventh night about the foresaid hour the blood brake out again in more quantity than it did aforetime, nevertheless the blood was stanched, and by the morn the patient was so taken with the cramp in the cheeks and in the arm that he might receive no meat into his mouth, neither could he open the mouth, and so vexing the patient. In the fifteenth day the blood brake out again, and in the eighteenth day the blood brake out again out of all measure, and alway the cramp endured forth, and in the twentieth day he died."

Arderne, like most of his contemporaries, details the qualities to be found in a successful surgeon, and drives his meaning home in a series of apophthegms. Amongst other things, let the chirurgeon "be found evermore sober, for drunkenness destroyeth all virtue and bringeth it to nought; as sayeth the wise man, 'Ebrietas frangit quicquid sapientia tangit,' 'Drunkenness breaketh what so wisdom toucheth.' Scorn he no man, for of that it is said, 'Deridens alios non inderisus abibit,' 'He that scorneth other men shall not go away unscorned.' If there be made speech to him of any leech, neither set he him at nought, nor praise him too much or commend him, but thus may he courteously answer: 'I have not real knowledge of him, but I learned not nor heard of him but what is good and honest.' And of this shall honour and thankings of each party increase and multiply to him; after this, 'Honour is in the honorant and not in the honoured.' In as much as he may, grieve he no servant, but get he their love and their good will. Abstain he him from harlotry as well in words as in deeds in every place, for if he use harlotry in privy places, sometime in open place

there may fall to him unworship of evil usage, after that it is said 'Pede super colles, pedes ubi pedere nolles.' When sick men cometh to the leech to ask help or counsel of him, make he covenant for his travail [agree upon the fee] and take it beforehand. But let him give no certain answer in any case unless he first see the sickness and the manner of it. Have a leech also clean hands and well shapen nails and cleansed from all blackness and filth. Hear he many things but speak he but few. For a wise man sayeth, 'It beseems more to use the ears than the tongue.' And in another place, 'If thou hadst been still thou hadst been holden for a philosopher.' Also it speedeth that a leech can talk of good tales and of honest that may make the patients laugh whilst they make or induce a light heart in ye sick man. Discover never the leech unwarily the counsels of his patients—as well of men as of women—nor set not one to another at nought although he have cause to do so, for if a man see thou hele [conceal] well another man's counsel he will trust better in thee."

Arderne appears to be the only contemporary authority for the story of the means by which Edward the Black Prince obtained the ostrich feather which has since become the cognizance of the heir-apparent to the English throne. The passage runs as follows: "We can not cure rhagades unless the remedy can be put through the anus either as a clyster or by means of a suppository, since remedies applied outside are either useless or do very little good. We ought, therefore, to wash with stimulating applications until the wound is clean, and afterwards with applications which both heal and dry, as has been already pointed out in the chapter on Internal Piles, to wit, where Nastar is painted—and Nastar is a kind of clyster or enema known as a clyster-pipe. The feather of the Prince of Wales is also shown there, viz., on the preceding page. And note that Edward, the eldest son of Edward king of England, bore a similar feather above his crest, and he obtained the feather from the king of Bohemia, whom he killed at Cressy in France. And he took the feather, which is called an 'ostrich feather,' which that most noble Lord King had used hitherto to bear above his crest. And in that year when our lord the strenuous and warlike Prince departed to God, I wrote this little book of mine with my own hand, viz., in the year one thousand three hundred and seventy-six. And our Lord Edward the Prince died on the sixth of June on Trinity Sunday at Westminster during the great Parliament, May God assoil him for he was the very flower of chivalry without peer in the world."

There is a curious sidelight on Arderne's experience of the profligacy of the times, when he directs, in making the styptic powder called pulvis sanguis veneris, that there should be taken "the blood of a maiden virgin, or of a damsel about 19 or 20 years which was never with child though she be corrupt, for now in this time virgins cometh full seldom to 20 years."

The illustration, showing a Master Surgeon operating upon a case of fistula in ano, is copied by the kind permission of the Trustees of the British Museum from a beautiful copy of Arderne's works preserved as Sloane MS. 2002. This manuscript was probably made in the early part of the fifteenth century for some noble patron.

SURGICAL PATHOLOGY OF THE PERIPHERAL NERVES.

By Captain SYDNEY M. CONE, M.O.R.C., U.S.A.

Since being placed by Colonel Sir Robert Jones in charge of the pathological department of Alder Hey, in June, 1917, all the knowledge of surgical pathology at my command, aided by valuable work done by others, has been utilized in an endeavour to solve the problems of nerve regeneration in war injuries of the peripheral nerves. To this end we examined macroscopically and microscopically tissues from more than two hundred cases.

Material from autopsies on fœtuses, adults, and guinea-pigs was used in studying the normal anatomy of nerves. Animal experimentation was carried out to show that the peripheral end of a torn nerve grew actively, and at the same time to give us an idea of the rate of growth. Nerve stretching and compressing experiments showed how one of the unsettled anatomical points (the Schmidt incisures) could be well explained, and also why the 'barbed,' 'beaded,' or conical appearance of the larger fibres was more commonly seen in nerves compressed and stretched in scar tissue than in normal nerves. They suggested, further, that these conical divisions of the nerve fibres, corresponding to the Schmidt-Lantermann incisures, had a physiological purpose —the continued insulation of the nerve when under stretch or pressure in normal movements. The distinct outlining of these divisions (conical segments) was best demonstrated by the neurokeratin stain.

The embryo and animal nerves also demonstrated that what we invariably saw in our pathological specimens as an axis-cylinder sheath was a normal structure.

By the animal experiments we were able to prove that the varicose and irregular branching appearance of the excised nerves indicated the youngest nerves, and that those with conical structures were older. We were also able to show that transplanted nerves grew about foreign bodies such as suture material—a fact which was also noted in the actively proliferating fibres in the pathological specimens. The transplanted nerves grew also in the presence of infection, a thing which we rarely noted in the human specimens.

One of the evident facts seen in our great amount of material was that nerves grew more readily in fat than in muscle; this was also demonstrated in the guinea-pig implants. That the blood-vessels, both active and thrombosed, were a common leader for the nerve fibres was noted in both the pathological material and in the guinea-pig experiments (*Figs.* 419, 420, 421). Granulation tissue, too, was demonstrated to be a fertile field for young nerve growth, the fibres following the vessels (*Figs.* 418, 447, 453).

The neurotropismus effect of neighbouring nerves on a cut or torn branch was proved when, in a specimen transplanted at some distance from the anterior crural nerve, new branching varicose tendrils were seen in granulation tissue growing about the crural nerve.

A negative result noted in the case of transplanted growing nerves likewise teaches a lesson. In none of the guinea-pig growths was there a tendency to dense formation of 'nerve callus,' such as occurs in the bulbous endings in scar tissue. No scar tissue formed in the experiments, and consequently the newly formed nerves were always seen as separated fasciculi or branching tendrils. It looks as if opposition to growth tends to make the nerve fibres more compact in arrangement, while not retarding their life properties greatly.

Some of the notable conditions in the pathological specimens concern the growth and the degeneration of nerves, vascular changes, phagocytosis, the character of connective-tissue formation in and about the nerves, the involvement of fat and muscle in nerve proliferation, the rate and location of nerve growth, the relation of nerve to enwrapping materials, the question of foreign bodies in nerves, the percentage of nerves in various parts of the excised nerve, the method of spread, and the age of nerves. These will be discussed in relation to the various portions of the excised nerve from which the section was taken, whether the central or peripheral end, the middle portion (usually the obstructing scar), or the surrounding adhesions. Much of interest to the histologist may be observed in the pictures from these different portions, in which young fibres will be seen.

Some of the most interesting findings refer to the question of nerve growth and degeneration in the distal end of a nerve completely separated from its spinal centre. The term 'nerve callus' will be seen to deserve its title, in specimens taken not only from bulbous ends and side bulbs, but also from within the nerve substance and from adhesions.

The phenomena occurring in a nerve graft will be found to be of interest. How sutures are taken care of will be seen in the guinea-pig experiments. That foreign bodies are no insuperable obstacle to new nerve-formation is demonstrated in many of the sections (*Fig.* 418).

METHOD OF OBTAINING MATERIAL.

The average time after injury before the patient came to operation was about eight months. A few were operated on three months after the trauma, others two years later. Most of the nerves were injured by shrapnel or bullets; some were torn by splintered bone; others were indirectly involved by secondary changes in surrounding tissues, whether bone, skin, or muscle, owing to adhesions pressing or dragging on the nerve.

The entire area of apparently changed tissue—nerve and surroundings—was excised *en masse* until good tissue was supposed to be left behind. The nerve-ends that were sutured are represented in our pathological descriptions by the letters P and D. P represents the proximal or central clean-cut section across the nerve, at a point where the surgeon thought he had good 'soft' normal nerve to suture to D, the distal or peripheral end, where the surgeon made a clean cut across the nerve at a point nearest its end-organ, whether skin or muscle. At the latter end also incisions were made across the fibres, or whatever was left by the bullet's ravages, until a soft, supposedly 'normal' nerve tissue was reached; of course we understand that at D real normal original nerve could not be reached in a badly torn specimen—torn enough to require

suture—for nerves degenerate throughout the distal portion as soon as disconnected from their spinal centres. What is described as D is the piece adjoining the distal end which the surgeon unites to the other end P.

Gross Appearance of Tissues.—The worst tissue is usually seen about midway between P and D, being where the surgeon had great difficulty in freeing the conglomerate mass of nerve, muscle, and scar tissue from surrounding tissues. This we label M; it lies between two bulbous masses, the bulb nearest P usually being the larger; it often appears like ordinary scar tissue. This tissue of the bulb is very hard, and grayish-white in colour; the cross-section is at the first view homogeneous, but careful examination will reveal a fine mottling, due to a slight translucency of innumerable fine gray points. This is what we call 'nerve callus,' and will be shown to be made up of great numbers of fasciculi of very young nerves, intertwining, and separated by connective tissue of varying amount and density. The figures show that the nerve fibres in every case exceed in amount the mass of connective tissue, and van Gieson's stain corroborates this (*Figs.* 430, 431).

When the nerve trunk is almost or completely severed, the proximal end is usually bulbed; the distal end is sometimes bulbed, but otherwise is pointed or jagged.

Sometimes, when the surgeon's dissection is completed, there may be seen nothing but a dense white constricted cord of tissue directly continuous with the nerve trunk, improving gradually in appearance to the point where the damaged nerve was cut at P and D.

There are various grades of constriction and jaggedness of appearance of the exposed old nerve, according to the amount and density of the adherent constricting scar tissue.

The section across the nerve at the central end, left for suture to the peripheral segment, seldom appears so definitely marked by bundles and so well defined by endo- and perineurium as normal nerve. Seldom do the bundles protrude on pressure as so many comedo-like excrescences, but there is a translucency about the definite bundles, due to protoplasmic and nuclear increase. Instead of the normal milky-white (Sir Renfrew White) definite lines or dots or masses of nerve funiculi, there is a pinkish-gray gelatinous appearance, as of a more vascular, proliferating, cellular nerve (the cells of nerve fibres, connective tissue, and blood-vessels being involved). Often one is compelled to suture a proximal end that has only faint markings of bundles—the proliferation of young nerves and connective tissue in the endo-, peri-, and epineurium so interlacing with the old bundles as to keep them homogeneously massed together. They are grayish-pink or grayish-white according to the preponderance of vascular or connective tissue.

The distal cut section is more commonly a homogeneous grayish-white mass, but is very frequently marked by funiculi—resembling the proximal section in every respect.

Not infrequently, after relieving the nerve of lighter adhesions, it is seen spindle-shaped, and grayish-pink or grayish-white in colour, depending on the vascularity, fibrous increase, or nerve proliferation in this symmetrical bulb. Again, a single knob, more or less irregular, may be found. Two knobs (side

bulbs) separated from one another by dense white connective tissue frequently indicate where a bullet cut through a half or a third of the diameter of the nerve, leaving the torn fibres to recoil and grow as bulbs of 'nerve callus.'

The study of this nerve callus, of the scar, the sutured ends, and adhesions, has been carried out by every available means. We have been most careful in marking the specimens to avoid confusing the P and D ends. A suture with a label carrying the number of the specimen was tied at the proximal end. and the specimen was immediately placed in 10 per cent formalin solution; any delay vitiates the results. Sections were made transversely and longitudinally from the proximal end (P), the distal end (D), and the middle (M) of the excised nerve, and from surrounding adhesions (Adh.).

METHOD OF STAINING SPECIMENS.

After six days' hardening in formalin (10 per cent), the pieces were carried through 80 per cent, 90 per cent, and 95 per cent alcohols, 100 per cent alcohol and ether (equal parts), thin celloidin and thick celloidin (one day each). They were then placed on blocks and cut 15 to 20 μ thick, preserving the sections in 10 per cent formalin.

The stain used was one devised by the writer, and is most valuable in demonstrating the youngest tendrils and showing the finest structure of the nerve fibres. It differentiates nerves from all other structures very definitely. Neurokeratin, the fibres' most important and most constant element, takes a brilliant mauve colour against an unstained connective-tissue background.* Blood-cells are brown, nuclei pink, muscle pink, and fat unstained. Keratohyalin and the inner lining of hair sacs alone take the mauve colour. This is an interesting comparative embryological and histochemical fact, for nerves are, like skin, derived from the epiblast.

The method may be summarized thus: Water 1 minute, carbol fuchsin (Ziehl-Nielsen) 10 minutes, water 1 minute, osmic acid (10 per cent) 5 minutes, water 1 minute, acid alcohol (2 per cent) 10 seconds, water 1 minute, alcohol (95 per cent) until colour ceases to come away, alcohol (100 per cent) and oil of cloves alternately until the section appears deep pink and translucent, xylol 2 minutes; mount in canada balsam.

This stain may be used very profitably in the study of all tissues except connective tissue. Even in the case of connective tissue we may, by modifying the length of time in osmic acid, get a deeper stain of the nuclei and connective-tissue fibres. A great deal of the value of the method depends on the proper handling of the acid alcohol. The thicker the specimen the longer must it be decolorized in acid alcohol. One must not forget that the decolorizing is continued in the alcohols used to dehydrate preparatory to clarifying in oil of cloves and xylol.

This method is not designed for material hardened in other agents than formalin, nor for paraffin work, yet I have manœuvred on occasions so as to get fair results when compelled to use such unsatisfactory material. Alcohol and picric acid specimens were improved by leaving them twenty-four hours

* Egg membrane, which contains much keratin, takes the neurokeratin stain deeply.

in formalin. Paraffin sections stain more advantageously when chloroform is used to dissolve the paraffin, but the results are uncertain at best. Frozen sections give excellent results.

Although the neurokeratin stain shows the nuclei fairly well, I found that the method used by Howell and Huber was better adapted to the study of the multiplication of the nuclei of Schwann's sheath and of protoplasm. Here I used picric acid fixation and Boehmer's hæmatoxylin as staining reagent. Many sections were stained by Stroebe's, van Gieson's, Bielschowsky's, Weigert's, and Williamson's methods. I used free hand sections and teased specimens in glycerin mounts; but as soon as the carbol-fuchsin–osmic-acid (neurokeratin) method was developed, I ceased all other ways of staining.

I found that the gentle teasing of the specimen when on the slide in xylol ready for balsam, helped me to see tendrils in scar tissue which might otherwise have been overlooked. I also found that tendrils could be teased and followed for 4 to 5 cm. after the tissue was hardened in formalin. Thus one was able to stain the specimen, which could not have been done if Kühne's sulphuric acid 'cooking' method had been used.

Referring to some irregularities in the staining of the sections, I would like to quote what Roussy and L'Hermitte say about the sensitiveness of nerves to chemical changes: "Nerves are easily modified, and are not readily studied post mortem, because of chemical changes. They little resemble live ones. It is necessary to use the same technique in making a comparison of normal and pathological nerves." I found that with similar specimens, treated by the same method, but varying the time in one or another reagent, the entire nature of the stain was changed. In the neurokeratin method, the nuclei will frequently stain deep-pink in very cellular specimens, the nerves not showing at all; if we now vary the length of time in the acid alcohol, we reverse the result. This fact was particularly noticeable when using aniline-oil fuchsin, osmic acid, and ammonia.

This same method (neurokeratin stain) was used in the case of many surgical pathology specimens in order to determine their nerve contents, as well as more definitely to discover the capacity and limitations of the stain. Some of the nuclear changes in relation to the axis cylinders and myelin, noted by Howell and Huber in their picric-acid–hæmatoxylin method, were finely shown by the stain. It looked very much as if the nuclei were transformed directly into the new fibres. Bethe and Bowlby also made this observation. It is not an axis-cylinder stain, yet the youngest fibres take a homogeneous mauve colour, as seen in the five-days-old varicose tendrils and bulbous tips growing in the granulation tissue and muscle of the transplants in the guinea-pigs (*Figs.* 449, 450). As seen in the pathological material (fibrous scars, adhesions, bulbs, and newly-formed nerve-tendrils in old fibres), the mauve stain outlines by parallel fine lines a pink centre in fibres 2 to 3 μ wide. When the tendril is narrower or younger, the colour is not in parallel lines, but is a homogeneous single line, bulbed here and there (*Figs.* 438, 440, 441).

Modifications in Staining and their Significance.—Not infrequently I have been unsuccessful in staining young fibres in very cellular tissues. Repeated efforts with modification of the exposure to acid alcohol were successful. Kennedy has had a similar experience (1904). Similarly, when using

aniline stains with ammonia, I not infrequently noticed that, of several sections (all nerve-containing) treated by the same process, one might be nicely stained while another was not stained at all. Roussy and L'Hermitte explain this by the exceeding sensitiveness of the nerve to chemical changes. The specimens were not chemically alike. I think that much of the misunderstanding of laboratory workers comes therefrom. Bethe goes so far as to say that when a fibre is acid-fast it is physiologically functioning. I have no doubt that others will have some trouble with the neurokeratin stain until they learn the proper use of the acid alcohol. I never learned to use Stroebe's aniline blue stain; Kennedy, too, had to modify it to suit himself. Because one does not see all structures present with a special stain, it does not follow that another method may not succeed in demonstrating more. It is a mistake to say, after the use of only one method, that other investigations are all wrong.

I think, with Roussy and L'Hermitte, the success of nerve staining depends on the immediate placing of fresh tissues in the hardening agent. Chemical changes take place very rapidly in nerve tissue.

HISTOLOGY OF NERVES.*

Axis Cylinder.—This I regard as a homogeneous material in a sheath of neurokeratin. It has been described as a fluid; a glassy jelly-like substance which forms granules (Arndt); a fibrillar substance (Bethe, von Bungner); it is composed of discs (Mitchell). Ballance and Stewart describe the young axis cylinder as beaded and sinuous, remaining immature until united to the axis cylinder of the central stump. I find a sheath about the axis cylinder at a very early age—even in its varicose state. That it requires nerves from its own central stump to cause it to reach maturity can hardly be the case, for Langley and Ranvier showed that other nerves can make connections with the cut nerves. Arndt says: "The axis cylinder is a cell body or row of such cells drawn out into a thread . . . a mass of protoplasm modified into a ground substance and granules surrounded by a sheath." The normal diameter is said by him to be $0{\cdot}5\,\mu$. The ground substance impregnates its surface covering, and this is neurokeratin.

Myelin.—This is said to be an insulator of the nerve (Halliburton, Howell, Moynihan). Howell and Huber see a possible relationship in the disappearance of the nuclei and the myelin formation. Kolliker states that the myelin formation is influenced in some way by the nuclei.

I have used the stains by means of which the myelin was studied by others With my stain the adult myelin structure in the medullary sheath is outlined quite clearly. Myelin is hard to see or to stain in the fibres 1–$3\,\mu$ in size. At the youngest period it appears as if there is no chemical differentiation of neurokeratin and myelin. The youngest (5 to 8-day) fibres stain homogeneously a deep mauve with the neurokeratin stain.

Joseph demonstrates an intimate blending of the neurokeratin network of myelin and axis cylinder. Kuhnt describes this as forming an axis-cylinder sheath $0{\cdot}1$ to $0{\cdot}15\,\mu$ thick. Tuckett believes that there is neurokeratin in the axis cylinder as well as in the medullary sheath. Kühne first described the neurokeratin framework of the medullary sheath.

Nageotte states that "myelin formation indicates maturation of a nerve (young neurites); they cannot function until myelinated." (See Howell and Huber as opposed

*Fuller details of this work will be published in the forthcoming number of the *Journal of Pathology and Bacteriology*.

to this view.) He states that there is an outer and inner myelin sheath (medullary and axis-cylinder sheath). Kennedy, who has done much to clear up the uncertainty surrounding our knowledge of nerve growth, writes of a "resting stage" of the young nerve fibre. At this stage, when it has no central connection, it does not acquire a thick myelin coat. It remains small for months, though "all the parts are represented." My work agrees with his findings. The nerves are seen in all my specimens from two months to two years after injury, even where they are only 1 to 3 μ in width.

Fleming, writing of the bulb 'neuroma,' says that the new fibres find their way with ease through the dense matting of fibres. The myelin suffers more than the axis cylinders.

Myelin Globules ('Vacuoles')—Schäfer describes a network of neurokeratin dividing the nerve irregularly as if by partitions. This framework is responsible for the so-called 'vacuoles' (globules of myelin), round or oval bodies outlined by a faint mauve line (neurokeratin), which I find invariably in medullated nerves. They are seen in the nerves of fœtus and adult, human and animal. These globules are well demonstrated in *Figs.* 408, 409, where the neurokeratin is deeply stained. Tinel refers to them as a 'gonflement' of myelin in the nerves, "making them looked vacuolated," but does not refer to the neurokeratin framework as responsible for their appearance. Tuckett and Joseph refer to the neurokeratin network of the medullated sheath passing on further and entering the axis cylinder. Ingebrigtsen refers to the fat-like globules (myelin) embedded in varicose accumulations of protoplasm located as a rule next to the nucleus. This was demonstrated by him in young nerves grown in Ringer solution. Arndt refers to the globules as occurring in atrophic and hypertrophic nerves.

The vacuolated appearance is more common in actively growing nerves. I find them in the nerves of the fœtus and in eight-day growths in guinea-pigs. There is no cause for confusing these bodies with degenerated material. They do not stain with the neurokeratin method—the border alone is outlined. I have seldom been able to demonstrate them in nerves from autopsies held after several hours, owing to chemical changes in the nerve. The balls that appear in degenerated nerves, called 'myelin balls,' take a deep black stain and are not outlined by a delicate mauve-coloured framework.

Conical Segments.—Adult fibres, 6 to 12 μ wide, invariably appear under the low power as barbed, beaded lines. With 350-diameter magnification one sees regular rows of cone-shaped mauve-coloured objects closely following one another; 10 to 40 μ is the usual length of these conical segments. Their bases stain deeper than their apices, and these latter seem truncated to fit round the central content (axis cylinder) of the fibre. The ending of this conical portion is cylindrical. It may be seen as a circle in cross-sections cut a little obliquely (*Fig.* 406). Similarly, the more deeply stained base of the cone, apparently attached to the sheath of Schwann, appears as a circle in appropriately cut sections.

The relation of these objects to Schmidt's incisures and the axis-cylinder sheath was specially studied. All nerves above 4 μ in diameter are seen to be made up of conical segments corresponding to the space between adjoining Schmidt-Lantermann incisures. These are seen invariably in the pathological material. They have been studied in the nerves of embryos, normal adult nerves procured from amputated stumps and autopsies, and in guinea-pigs' nerves. They appear most definitely when the nerve has been stretched or compressed. This I demonstrated by stretching nerves of stumps and guinea-pigs, and placing them at once in formalin or osmic acid with control nerves (the neighbouring nerve or intact half of the stretched nerve). Slight post-mortem change will interfere with the most distinct outlining of the cones. The stretched nerve is seen, either in glycerin or after hardening, humped at regular intervals (40 μ) as if to receive the portion of nerve following it. In stained sections this gives an invaginated or intussuscepted appearance (*Fig.* 405), the intussusception corresponding to the location of the incisures of Schmidt, which may be seen in osmic acid-hardened specimens as unstained oblique lines passing from the neurilemma sheath to the axis cylinder.

There is no doubt about these cones being normal anatomical constituents of the nerve fibre (*Fig.* 440). Under the same methods of examination they always appear alike in similar conditions of age, size, normal or pathological state. I believe, with Howell and Huber, that the growth and degeneration of myelin in segments is regulated by the Schmidt incisures, which are the boundary lines of these cones. Their limitation is due to neurokeratin material. They are doubtless the means of insulating the nerve, as described by Halliburton, Howell, Moynihan, and others.

Experiments to show Nerve Segments.—Normal nerves were examined fresh, in salt solution, in glycerin, and after hardening in formaldehyde. A suture was fastened to each end, one of these being tied fast to one side of the mechanical stage of the microscope, the other being used to stretch or relax the nerve. Electric-light illumination demonstrated the incisures as bright lines, the surrounding tissue interfering with the ready passage of light. Two incisures pointing toward one another were selected for observation. As traction was made, the lines of light, which had originally reached the axis cylinder at an acute angle, seemed to approach from the neighbouring incisures, forming a cylinder of light for the greater distance between the original bases of the incisures. The bases could, however, always be seen as such. After stretching, the outer border of the fibre was seen to be humped at the bases of these cones of light, growing narrower at the part of the fibre corresponding to the more pointed part of the cone, giving an intussuscepted appearance. The nerves were stained after completing the experiment, and when they had not been overstretched or torn, elongated cones were clearly demonstrated. Seen in the pathological material, they differ in no respect from the above. They are not pointed, but appear as truncated cones. Golgi refers to them as funnels outlined by neurokeratin. They are always present in the wider (6 to 12 μ) nerves of our pathological material, and seem more distinctly outlined than in normal nerves. Schäfer pictures them in the 1916 edition of the *Essentials of Histology*.

They were noticed by us in our early work, but were not so systematically or definitely pictured until stained by the neurokeratin method. Ranvier refers to "renflements biconiques" occasionally seen. Tinel writes of nerve fibres as "hérissées d'épines," "barbelées" (barbed), when stained with silver nitrate. He evidently saw the stained incisures—the stain not penetrating along the entire structure. He says correctly that his barbs are incisures of Schmidt-Lantermann. Stroebe and von Bungner and many others are still disputing about the Schmidt incisures, questioning whether they be real or artifacts. I have no hesitation in agreeing with Schmidt, Schäfer, and Golgi. The photographs (*Figs.* 405, 406, 407, 408) demonstrate them well in longitudinal and oblique sections. The Schmidt incisure is the base of the cones or funnels. The incisures are usually pictured as narrow oblique lines placed every 40 μ along a nerve and penetrating as far as the axis cylinder. They go farther, as my stretching experiments demonstrate. The stained specimens show these lines continued alongside the axis cylinder as a sheath (*Fig.* 407). They are more faintly stained as they approach the next cone base, but never completely lost to view. I originally described them as truncated cones, but think Golgi's term 'funnel' is a better one.

We thus have an explanation of the structure of the incisures of Schmidt, Tinel's barbs, and the axis-cylinder sheath, all in one. All belong to the neurokeratin framework, which also is responsible for the 'vacuoles' when it sends finer branches amid the myelin sheath (Schäfer). The length of these cones varies under changing conditions of stretching or pressure. They are regularly placed, and measure 40 μ in length as a rule, but I have seen them, symmetrically placed, measuring 10 μ from base to base. I have stained them in many different ways, but in none of the specimens is the entire body of the cone demonstrated so clearly as in those stained by the neurokeratin stain.

Golgi states that in order to demonstrate these 'funnels' the nerve should not have been stretched. In my original observations on autopsy material, I stated that "too much stretching defeats our object, especially in the material removed at

autopsy, for in these cases there is a modification of the tissue produced by post-mortem changes."

Varicosities.—The young nerve is recognized by its size, shape, and spiral winding or branching from another fibre. In its youngest form the myelin coat has not as yet been added. It is the characteristic varicose appearance which is most striking. Many observers have studied these peculiar irregularities. Some look upon them as evidences of degeneration. With the neurokeratin stain, the tendril, when degenerated, is broken, with sharply angular outlines, it stains irregularly (not mauve), and is granular. I have seen enlargements of the tendril due to the pressure of a neighbouring nucleus. Ingebrigtsen pictures such fibres. Arndt's explanation is that the imbibition of fluid may sometimes cause the irregularity. This may exaggerate the condition, for I find this appearance most marked in hæmorrhagic and œdematous nerves. Schmidt thinks that gas causes the swellings. Tuckett believes that poor hardening is responsible, and that they are post-mortem artifacts. Wilson says they occur normally at points of branching, on the axis cylinder or where the fibre is more subject to external influences. They are not artifacts as a rule. Ingebrigtsen photographed them growing in vitro, and they are seen in sprouting tendrils of young branching nerves in my guinea-pig transplants (*Figs.* 444, 446, 449, 450, 457). It is quite possible that the irregularity of pressure a delicate fibre is subjected to in winding through tissue of varying density may be one of the many causes of its unevenness of structure. The fibres are not always varicose. One often sees straight and varicose fibres in the same microscopic field.

NERVE DEGENERATION.

By the time our cases were operated on, the Wallerian degeneration had run its course. The myelin had gone through the fragmenting and balling processes, and been carried off by phagocytes or in the lymph stream as fat (MacDonald). Langley says that traumatic degeneration is seen up to 100 days. Kennedy says it may be many months before all the degenerated material disappears. Occasionally I have found black-stained balls of myelin in the old fibres four months after injury. Before myelin balls form, the cones become granular and stain irregularly. At this time protoplasm with innumerable spindle-shaped nuclei fills the old sheath-of-Schwann sac, now empty of its original nerve. Many young fibres are seen in this protoplasmic syncytium before the degenerate products have gone. This is readily understood if, with Nageotte, Kirk and Lewis, and Ingebrigtsen, we believe that regeneration depends on a preceding Wallerian degeneration (*Figs.* 410, 412).

In a recent case, constriction of the posterior tibial by a mass of dense cartilaginous connective tissue produced all the typical products of Wallerian degeneration in the portion of the nerve distal to the ring of tissue, a few nerves remaining intact; this was two months after injury.

Langley used methyl blue to stain axis cylinders. An hour or two after the nerve was cut, the axis cylinder stained a deep even blue. In ten days it appeared less regular. In twenty days it stained less deeply and the boundaries were not sharp. In thirty days there was no stain. He believes that neurilemma cells are phagocytic, absorbing the degenerated myelin, that there are different rates of degeneration in the different kinds of nerves, and that small nerves resist degeneration longest. Weir Mitchell, Remak, Bidder, Korybutt-Daskiewicz, Wolberg, Schiff, Howell and Huber, Phillipeaux and Vulpian, and Erb believe that the axis cylinder remains intact during degeneration of the medullary sheath. Neumann and Eichhorst hold that the axis cylinder undergoes changes, and fuses with the myelin to form a new nerve fibre. Erb joined them in this view later. Howell and Huber say: "Most writers think that the axis cylinder goes to ground with the medullary sheath." Degeneration occurs in the peripheral end after section. First it occurs in the segments (Schmidt-Lantermann's), then balls of myelin form.

Phagocytes.—My specimens show giant cells, epithelioid cells, pigment cells, and leucocytes, all acting as phagocytes. It has been said (Keen, Langley, Stroebe, Mott, Halliburton, and Edmunds) that the neurilemma-sheath cells act as phago-

cytes. Mott, Halliburton, and Edmunds note with others that later they join end-to-end like embryonic nerve fibres. Most observers look upon them as nerve cells (neuroblasts) with a specific function. When proliferating, they resemble connective-tissue cells so closely that it is impossible to distinguish them. It is in their quiescent condition, before and at the end of proliferation, that their elongated staff-shaped nuclei, containing more chromatin, may differentiate them.

When von Bungner said that 'wander cells' and leucocytes were seldom seen, he was dealing with experimental material. In work done in Kühne's laboratory on nerve degeneration, I not infrequently saw leucocytes engulfing myelin débris. It was not so common, however, as one would expect from what one finds in the removal of foreign material from other tissues than nerves. I never saw what I could call a Schwann-sheath cell acting as a phagocyte. Tinel says Schwann-sheath cells, connective-tissue cells, and leucocytes carry away the débris. In photographs by MacDonald representing fat removal in peripheral nerve degeneration, the globules as such are seen in septa between the bundles.

Neurilemma-sheath Cell-proliferation.—The most marked definite neurilemma-sheath cell-proliferation may be studied in the nerve fibres which have lost their normal contents by Wallerian degeneration. This involves the entire distal portion of a severed nerve, and extends as far as the first or second node of Ranvier of the proximal segment.

It is seen best in our early cases (three to four months), where there still is evidence of degeneration products, in the shape of myelin balls, in the nerve fibre. The appearance is that of a great number of protoplasmic circles with several nuclei in each. These circles are swollen, closely pressed together, and might be compared to an alveolar sarcoma with unusually symmetrical alveoli and a limiting circular wall (epineurium). When cut longitudinally, the nuclei are most prominently seen as spindles or elongated staffs, very closely bunched. Sometimes there is no evidence of protoplasm, in which case one is most apt to find new varicose nerve-fibres present among the nuclei. Rows of these nuclei look like fasciculi composed of nuclei instead of nerves—the old fibre delimiting the new fasciculus. This is exactly what happens, for I have followed such rows of nuclei along until there was seen a transition to young varicose nerve-tendrils. Again, my first stains showed no nerves, but repeated efforts demonstrated a few young tendrils among the nuclear mass.

In a 35-day transplant, such fasciculated rows of nuclei were seen to branch, and could be followed to a point where there were tendrils of varicose young nerves in place of the nuclei. The nuclei stained less well as one approached the area of nerve budding. There were still evidences of a few faintly-stained nuclei among the tendrils. These nerves were branched and bulbous at their ends, and appeared varicose—with deeply-stained bodies, half the size of a nucleus, attached to them. They were vesicular and deeply stained by turns. Some of these irregularities gave the appearance of nuclei flattened against one another at their ends—the junction being biconical and circular. (See Halliburton, Mott, and Edmunds, Ziegler, and Galeotti and Levi.)

The newly formed tendrils appear on cross-section as circles, 1 to 3 μ in size, homogeneously stained or as rims of mauve colour with a pink centre (*Fig.* 420). Thicker specimens may give the appearance of stamens protruding from a flower (*Fig.* 411). As the new nerve forms, the nuclei disappear (*Fig.* 450). Howell and Huber state that as myelin forms many of the nuclei go. They infer that it is possible for the nuclei to undergo a "myelin degeneration." I would suggest that it is much more likely from chemical analogy for the nuclei to be directly transformed into the nerve tendrils. Both contain a keratin element. Physiologically, too, they have their relationship, the nucleus controlling the trophic condition of the containing cell. Howell states that it is through the nucleus that the trophic (nutritive) influence of the nerve centre is transmitted.

The nuclei in most of my specimens are long spindles. They are very often staff-shaped (see Stroebe and Nageotte). They are better studied by Howell and Huber's method, in which the protoplasm about them is also stained as granular

lines, 1 to 2 μ in size, gradually tapering to a point and continuing for a distance of 80 μ. Frequently the nuclei look as though they were budding, and my neurokeratin stain shows a similar appearance, though not so distinctly. I think this question of nuclei in their relation to axis-cylinder growth will be well worth study.

I have never seen the ganglion-cell nucleus described by Gluck. Giant and multiple nuclei as described by von Bungner have occasionally been present. Eichhorst says that in degeneration of the nerve the nuclei change in shape from spindle to round.

We have never been able to trace a change from protoplasm into the formation of nerve fibres or myelin. We see nuclei in a wild state of proliferation in greatly increased protoplasm. The next stage noted is less protoplasm and more nuclei, the latter taking the form of the old fibre *en masse*. Then we finally see young tendrils crowded among nuclei and protoplasm, the nuclei much decreased in number, the protoplasm disappearing.

I cannot well see why Howell and Huber should think that Bowlby mistook nucleoli for axis cylinders. The nucleoli can seldom be well demonstrated in nerve work except by their own stain. In my work they are very faintly stained. All the round objects 1 to 3 μ in size which are seen stained mauve within the old nerve fibre are new nerves. Not infrequently the tendril has developed to such a size that one may see the pink axis cylinder in the centre of a mauve-coloured rim. Van Gieson's stain shows nuclei black, protoplasm brown, myelin and axis cylinder unstained.

Luciani, quoting from Ranvier, Vanlair, etc., refers to the arrangement of the neuroblasts of the neurilemma sheath in a chain, the nuclei being spindle-shaped. Benecke describes variously shaped nuclei. They always have a little protoplasm around them. Many of them are quite long. He describes them as being connected by thread-like processes when the nucleus itself disappears. This fibre now broadens, while a sheath gradually forms about it. His description of the occurrence corresponds with that of others (Galeotti and Levi), but his interpretation is different. Galeotti and Levi describe the proliferated nuclei of the sheath of Schwann as round or oval, containing more chromatin than normal. They were originally long. "The proliferating cells resemble embryonal cells in the development of nerves." Its stain differentiates this cell from a connective-tissue cell, and its action it that of a neuroblast. They used the salamander tail, as Harrison did, and grew young nerves which they saw form by a fusion of neighbouring cells. These were rich in nuclei, symmetrically placed. The protoplasm was hard to see, and finally disappeared, leaving the nucleus alone. Rows of granular material were now seen united as axis cylinders. Von Bungner describes the nuclear proliferation of cells of the neurilemma as at its height in five to eight days, one nucleus for each segment. He says, "These nuclei are surely of nerve nature, and must be called neuroblasts." Gluck describes rows of nuclei between young fibrils. Mott, Halliburton, and Edmunds refer to the elongation and multiplication of nuclei early in degeneration. They are arranged connected end-to-end, "looking like embryonic nerve fibres." They do not believe, however, that they form nerves.

NERVE REGENERATION.

All the material investigated showed new nerve growth in one or another part. The lowest percentage of nerve findings in either P, M, D, or Adh., was 82 per cent, in adhesions. Sometimes this included full-grown, old, good nerve trunks. I cannot imagine a case such as comes to the Alder Hey operating table not showing some young tendrils in the pathological specimen. These operations are delayed purposely until all danger of infection from the old infected wound has disappeared. In the meantime there has been a prolific growth of young fibres everywhere. It is not only from the main injured trunk we find nerves growing at various points (P, M, D, and Adh.), but like-

wise from other surrounding smaller nerves to muscle and skin. These are seldom considered. Langley and Ranvier pointed out long ago how experimenters (Vulpian and Bethe) overlooked the possibility of having cut other nerves than those experimented on, thus vitiating their results. I have seen small adult nerve trunks, as well as bundles of actively-growing young nerves, in the adhesions removed from about the scene of nerve severance.

Neuromas of Nerve Ends.—The nerve bulb, found at the end of the proximal segment, distal segment, on the side of a nerve, or as a cylindrical enlargement of the trunk, is the place where we may expect to see the most prolific growth. The same kind of growth and appearance is found here as is seen on the ends of nerves of amputation stumps (amputation neuromas). Alexis Thomson has enlightened us on this subject. Bowlby, Kennedy, Gluck, Eichhorst, and many others, have used the term 'nerve callus' to describe this young nerve material about the nerve ends. In 1887 Bowlby not only drew attention to the analogy between this nerve callus and bone callus, but thus early demonstrated new growth in the distal end.

It has been a difficult matter to convince many that there are fully formed nerves in either end bulb. Now it is scarcely questioned that these nerve callus masses are full of nerves containing axis cylinders. (Appended are photo-micrographs of nerve callus from various locations (*Figs.* 429, 430, 431, 433). Some are stained with the neurokeratin stain and also with Bielschowsky's axis-cylinder stain.)

The gross appearance of these wildly growing, coiling, twisting nerves is that of dense scar tissue. It is dense, grayish-white, hard, nodular (as a rule), and is most commonly seen at the ends of nerve trunks. It may be found, however, wherever the epineurium has been torn through to the nerve fibres. It is frequently situated between nerve trunks and in the adhesions near by (here it probably ends an overlooked injured skin or muscle branch). Not infrequently the homogeneous grayish-white surface of the cut section is mottled by pin-point dots or larger translucent grayish-pink areas of cellular nerves. It is also found extending about the nerve trunk 2 to 3 cm. from the end bulb.

I cannot add much to what Kennedy wrote about the microscopic pathology of these growing masses of nerve. I must accentuate the fact, however, that in all of my sections of nerve bulbs there was more nerve than connective tissue; as a rule they consisted of three-quarters nerve and one-quarter connective tissue and vessels.

The microscope demonstrates the homogeneous mass to consist of interlacing fasciculi of young nerves, the fasciculi varying in size from 10 to 50 μ in diameter. The nerves making up these small bundles are young varicose fibres 1 to 3 μ in size. Sometimes one finds larger ones mixed with these. The larger fibres are coned, and measure 6 to 8 μ. Where one sees larger fibres running parallel and bound together in bundles, they usually belong to the original trunk from which the others spread. As a rule this is seen to one side and away from the tip of the bulb. Sometimes they are found at the very tip, for the trunk not infrequently coils around as a whole before sprouting at the end.

The interlacing of the fasciculi is the most characteristic appearance, but we not infrequently find single tendrils growing wildly in the surrounding

tissue (*Figs.* 417, 438). They are varicose, bulbed at the end, frequently branch, and course in a spiral manner. The surrounding, supporting tissue is as a rule cellular, vascular, wavy connective tissue, not loose areolar tissue: it is rather compactly built—more so than one usually finds the case with cellular connective tissue. I take it that many of the spindle-shaped nuclei are nerve nuclei from the proliferating cells of the sheath of Schwann (see Tinel). There are always great numbers of nuclei among the fibres. Sometimes they are seen as staff-shaped nuclei, again they are spindle-shaped. This seems to depend on the stage of regeneration in which we find them. The varied description of these nuclei by competent pathologists must mean that their size varies greatly according to age. I have frequently seen them so numerous as to resemble a leiomyoma of the uterus, and Busse has also noted this.

I have not been able to make the distinction mentioned by Tinel between a true neuroma of the proximal stump and a glioma of the peripheral stump. This distinction was based on some of Nageotte's work. Since the publication of Tinel's book (1916), Nageotte has concluded that the fibres which he called neuroglial are really amyelinic axones (axis cylinders) from sympathetic nerves of blood-vessels; consequently the growth they form cannot be called glioma.

Van Gieson Stain.—This was used to demonstrate the difference between connective tissue and nerve. One specimen happened to be a very good one for the purpose. It was cut longitudinally through the entire exsected piece. The neurokeratin stain demonstrated the distal segment to be a dense mass of interlacing fasciculi of tendrils 1 to 3 μ in size, surrounded by many proliferating neurilemma-sheath cells with elongated nuclei. The proximal end was fibrous. With the van Gieson stain the nerves' side of the section (D) takes a brown colour; this is because of the great amount of protoplasm about them (nerves themselves do not take this stain). The fibrous-tissue (proximal) part of the section stains pink.

Rapidity of Growth.—The five-day and eight-day growths in guinea-pigs showed that the varicose tendrils could form fasciculi in this time. The fibres had wound their way into the skin and muscle at least 4 mm. distant from the implant. Ingebrigtsen saw the tendrils grow in vitro 500 μ in six days. Tinel says they grow 1 to 2 mm. a day.

How do Nerves Regenerate?—That the central end of a divided nerve is most active in regeneration is not questioned. Ranvier's original dictum that tendrils branch from the neighbouring nodes, two or three distant centrally from the cut, is accepted. Many writers state that they have seen the peripheral end regenerate also. The questions in doubt are:—

Does the distal end regenerate? If so, do these fibres mature? What causes them to mature? Can they mature without a spinal-centre connection (i.e. by autogenesis)?

What do new nerves come from? From neurilemma-sheath cells, or directly from old fibres? From ganglion cells? From connective-tissue cells? From leucocytes? From red blood-cells? From old fibres in which axis cylinder and myelin sheath have fused to form a new fibre?

Do nerve grafts grow *in situ*? Do catgut or other grafts carry anything which can form new nerves? Do the Schwann-sheath cells wander?

What action has the protoplasm of the neurilemma-sheath cell in nerve regeneration ?

Is chemotropismus (neurotropismus) a factor in stimulating new growth ?

Some of these questions will be discussed briefly.

Does the Distal End Regenerate ?—Kennedy, Bowlby, Langley, Howell and Huber, Ballance and Stuart, Tizzoni, Catani, Galeotti and Levi, von Bungner, Mott, Sherrington, Wolberg, Korybutt-Daskiewicz, Hertz, Neumann, Wieting, Sedgwick, Eichhorst, Benecke, Bethe, Weir Mitchell, Vulpian and Phillipeaux, Hjelt, all believe that it does. Many of them raise the question whether central connection is necessary for such regeneration. Some believe that the nerves will become what Howell and Kennedy call embryonic fibres, and go no further until connected with spinal centres. Some believe that the nerve goes on to maturation without spinal (central) connection. It is difficult to find anyone who holds that there is no regeneration in the distal end. The spinal connection is easily explained. Langley and Ranvier pointed out the readiest method when they disproved Vulpian and Bethe's proofs of autogenic new growth to maturity. Their evidence indicated that neighbouring nerves of skin or muscle made the central connection. Langley says non-medullated fibres may make the connection.

The author has demonstrated four methods of connecting the distal with the central or spinal fragment, thus giving the embryonal nerves an opportunity to mature : (1) By neighbouring nerves, torn at the time of the original injury ; (2) By a strand of undamaged, overlooked nerve still connecting the central and peripheral stumps ; (3) By nerve fibres which have worked their way through the scar ; (4) By adhesions carrying nerves around (bridging) the scar.

In Woolsey's opinion the fact that the axis cylinders of the spinal cord do not regenerate when cut, supports the view that the peripheral end regenerates from neurilemma cells—there being no such cells in the cord, regeneration after section is not possible.

Baer, of Johns Hopkins University, in a personal communication, informs me that he finds that the Schwann-sheath cells die in anterior poliomyelitis. This might partly explain why the nerves do not recover in this disease. This evidence has its negative value in helping to prove the regeneration of the distal end from the neurilemma-sheath cells.

Do the Distal Fibres Mature ?—In 86 per cent of the specimens from the distal end stained by the neurokeratin stain nerves were seen. In the majority of cases they were in fasciculi. Sometimes bundles of full-grown fibres had formed. Frequently single varicose tendrils were seen, following blood-vessels, or discrete in cellular connective tissue. Bielschowsky's axis-cylinder stain demonstrated axis cylinders in every case when it was used as a control. Not only do these axis cylinders stain well, but, as my guinea-pig transplants show, they proliferate actively.

There are a few cases in which sufficient time has elapsed for the results of operation to appear. In some of these—the earliest good results—both ends contained only fasciculi of fibres 1 to 3 μ in size. A future report will compare clinical results and pathological findings.

Can the Distal Fibres Mature without Central Connection ?—Among those

who believed in such a discontinuous formation of nerves were Remak, Heller, Benecke, Eichhorst, Neumann, Hertz, Leegard, von Bungner, P. Ziegler, and Virchow. Bethe thinks disconnected fibres can mature, though he admits that they are more likely to reach full development when stimulated by central association. He describes degeneration in many of his 'autogenic' nerves when they are left too long disconnected. He found it necessary to use very young animals in order to get good results.

Whence do the Young ('Embryonal') Nerves Come?—We shall not discuss the theories of connective-tissue, red blood-cell, and leucocyte origin promulgated by Benecke, Hertz, and Hjelt (who considered the nuclei of the neurilemma to be connective-tissue cell nuclei). Most of those who believe in a discontinuous origin of nerves, ascribe their beginning to cells of the neurilemma sheath. Hjelt, Stroebe, Kolliker, and Benecke take these to be of connective-tissue origin. Galeotti and Levi can distinguish them from connective-tissue cells in the salamander. Von Bungner considers them to be nerve cells. Ziegler and Gluck hold them to be ganglion cells, and Gluck calls the mass "nerve granulation tissue." Whatever they be called, the writers were all doubtless describing the same thing. That the nuclei and cell protoplasm are of varying size and arrangement at different stages in the proliferation is noted in my own experience, as well as by Stroebe, Benecke, and von Bungner. These authors observed the varying size and shape of the nuclei of the neurilemma sheath. The protoplasm, in order to form the irregular masses giving origin to myelin (Howell and Huber), and to form the strands and syncytium (Nageotte, von Bungner, Kirk and Lewis, Ingebrigtsen), must alter its size considerably.

It has also been pointed out by Eichhorst, Hertz, Mott, Halliburton, and P. Ziegler that the nuclei are arranged in rows, seeming to be connected or fused end to end. This arrangement was seen in a number of our sections in an apparent transition to young fibres. Eichhorst refers to a number of workers in nerve pathology who ascribed the origin of the nerve to a fusion of nuclei—Bowlby, Virchow, Nasse, Waller, Laveran, Robin, Einsiedel, Oehl, Luys, Weismann, Foerster, and Bruns.

Kennedy, Kirk and Lewis, Ingebrigtsen, and Galeotti and Levi suggest that the proliferating cells of Schwann's sheath grow into the scars of divided nerves. That the neuroblasts from the neurilemma sheath carry (by migration) the nerve growth to other parts, is indicated in my guinea-pig experiments. ***Fig.*** 444 shows two distinct growths, one near the scar, another an inch away. In this and other guinea-pigs, new growth is demonstrated in the fat about lymph glands (***Fig.*** 452).

If the neuroblasts wander, the answer to the question whether grafts are of value is simplified.

Finotti, Keen, Gluck, and Sydenham have successively bridged large gaps between nerve ends with catgut or silkworm gut. Nageotte determined that a homoplastic graft of nerve differs from a heteroplastic piece only in being a little faster in myelinization. He grafted with good results nerves preserved in formalin or alcohol.

Langley says that all the medullated fibres in the peripheral ends of cut nerves are fibres which have become connected with the central nervous

system. If autogenic regeneration of fibres occurs, every one of them must have become connected with the central end of some fibre. This he states in criticism of Vulpian and Bethe's autogenic growth theory.

The neuron, according to Bethe, is not a functional unit—the ganglion cell is not essential. "After degeneration of the axis cylinder, the cells of Schwann's sheath proliferate, forming much protoplasm. An axial strand and peripheral sheath form—if one prevents healing of the cut ends of nerves in young animals a perfect regeneration may be forced." The formation of the axial strand from the protoplasm of Schwann-sheath cells is commonly accepted. Vulpian says (1859), "Transplanted nerves grow autogenically," and later (1874), "A nerve may get its trophic influence in other gray matter than that of the nerve to which it belongs."

Adult and Young Nerves.—It is obvious that a differentiation of nerves according to age might be of value. Data obtained from experiments on guinea-pig transplants and torn nerves, pathological material operated on at varying periods following injury, fœtal nerves, and normal nerves from autopsies, lead to the following conclusions.

When nerves are arranged in bundles with parallel fibres, they may be expected to contain full-grown fibres. Many of our specimens demonstrate, however, that these old bundles have lost their original contents, which are replaced by nerves in various stages of new growth. These bundles are never so compactly built as normal ones—i.e., with nerve fibre apposed to nerve fibre, showing as well-defined circles 10 to 12 μ in size, with a scarcely appreciable endoneurium. They commonly appear as a nucleated protoplasmic mass divided more or less indefinitely into swollen circular areas corresponding to the original fibres. There is an increase in endoneurium in all stages of regeneration, from connective-tissue cells to dense connective tissue, separating the individual protoplasmic nucleated masses, which replace the old fibres.

In a later stage one may see nuclei in such profusion as to simulate a spindle-cell alveolar sarcoma, except for the fact that the wider view shows the thickened peri- and epineurium defining the nerve. Such masses stain best with Howell and Huber's picric-acid–hæmatoxylin method, but it is by the neurokeratin stain that one can be sure of what these nuclei and protoplasmic masses represent. By this method one not infrequently sees varicose mauve-stained tendrils among the nuclei. These increase in number as the protoplasm and nuclei decrease (see Howell and Huber's work referred to later, also Kirk and Lewis's reference, and others), until we see bundles made up of fasciculi of ten to twenty tendrils, each fasciculus representing an old nerve fibre (*Figs.* 410, 413). The fasciculi contain the finer tendrils 1 to 2 μ in width, and fibres 4 to 6 μ in width, with conical segments 20 to 40 μ long—these latter are more fully-grown fibres which will soon reach their full size, 10 to 12 μ.

Many of the fibres must degenerate from the pressure of growth, and this can indeed be demonstrated by the irregular staining and breaks in outline of many young fibres.

In some of our specimens cut longitudinally we can trace fasciculi of elongated nuclei to a point where mauve-coloured tendrils are seen. At the same time there is a marked decrease in the number of nuclei—"as the new nerve forms many of the nuclei disappear" (Howell).

In the guinea-pig experiments the varicose bulbed appearance of the young branching fibres is well shown.

In loose, non-restraining tissue, the spiral winding of the fine young tendrils helps one to pick them out. Discrete twisting young fibres can be seen between muscle bundles (*Fig.* 457), around hairs (*Fig.* 451) and along blood-vessels (*Fig.* 453) in the photomicrographs of guinea-pig transplants. One of the pictures shows what looks like a direct transformation of nuclei into nerve tendrils, portions of nuclei and entire nuclei remaining attached alongside the fibre. Some of the points of deeper staining resemble the bases of the cones seen in adult nerves, and look as if two nuclei might have fused at this point.

Sheath of Schwann.—It has appeared to me that as the new tendrils grow discrete in the connective tissue they pick up a fibrous sheath. The Schwann-sheath nuclei which remain from the great mass that were present a short time before, are seen resting against this new sheath like a secondary fixture and belonging to the nerve proper. This same method of acquiring a neurilemma sheath occurs to those tendrils which are in fasciculi, the connective tissue cells being seen only in the larger fasciculi. They do not acquire a sheath so long as conditions of pressure are such as to prevent new connective-tissue growth (e.g., in dense nerve-callus).

Neurotropismus, and the Trophic Influence or Direct Action of Protoplasm in giving Direction to Nerves.—There are certain influences causing nerves to grow or take a certain course. We have referred to the physical effect of the guidance of blood-vessels and the blocking by scar tissue. Vanlair used bone pathways to direct their growth, believing with Ranvier that nerves follow the line of least resistance. Forsmann, investigating the phenomena of nerve growth, noted: "It takes many fibres to give a notable functional result. Many err on their way (following section). They are seen in the surrounding tissues at the cut, and further central. They can err even after crossing the gap. It is remarkable that so many continue along the old nerve path." He experimented with the idea of solving the problem. In one of his experiments, in which he placed the nerve in a 'straw' tube with brain at the other (upper) end, the nerve grew toward the brain. In the next experiment no brain was placed at the opposite end of the tube, and only a few fibres found their way up the tube. This is due to what Langley calls neurotropismus (chemiotropic influence). Ingebrigtsen, Kirk and Lewis, and others interpret it as indicating that the syncytium of protoplasm from multiplying neurilemma-sheath cells guides the nerves. Bidder long ago stated that cut nerves, when sutured, break away to join their mates. Elsberg calls attention to a most interesting phenomenon which doubtless has a similar explanation. If a nerve to a muscle be cut and be implanted with another (foreign) nerve into the muscle, the original nerve alone makes connection.

These facts will explain many of our observations. Note in *Fig.* 450 the young nerves in granulation tissue around the anterior crural nerve some distance away from the original implant. One specimen pictures a nerve growing in a thrombosed vein, with small nerve trunks on both sides. Great numbers of young tendrils are seen in the walls of the vein, doubtless attracted by the neurotropic influence without.

Keen, Gluck, Finotti, and others use catgut to bridge gaps. Here both Vanlair's and Forsmann's influences are concerned in guiding the nerve. Nageotte has more recently made use of nerves preserved in formalin or alcohol to help the two ends meet.

Luciani refers to the neurotaxis (chemical stimulus) of degenerated nerves in the growth of young tendrils. Others, notably Ingebrigtsen, have shown the great influence of Wallerian degeneration in stimulating the sprouting of nerves. Ingebrigtsen found that he could not get transplants to grow in Ringer solution before they had been cut and left *in situ* five days. In my guinea-pig experiments the transplants grew at once. Vulpian's implants did not begin to grow for six months. My implants were taken from old injured nerves that had gone through Wallerian degeneration and had begun new growth. Vulpian transplanted normal nerves. Nageotte, in writing of the 'gliomata' at the end of a cut nerve, stated that they contained no axis cylinders, but that the fibrils possessed 'tropismus' like nerves. Since then I judge he has accepted this as an additional proof that he was not dealing with neuroglia, but with real nerves and axis cylinders. He now says that what he originally called neuroglia fibres are "amyelinic axones."

The Fibrous Scar.—The scar that is said to be the *bête noire* of the surgeon is between the ends of the severed nerves. Its centre is sometimes called 'chéloïde nerveuse,' a name given it by Dejerine. I find it no different from any other scar tissue, except that it seldom becomes sclerotic. Densely-growing tissue of any kind makes it difficult for nerve to pass through. Nerves may be turned aside when their ends reach an already prepared buttress. It is quite natural that unless the nerve fibres have grown *pari passu* with this connective tissue, an entering wedge will be next to impossible; it must be made when the tissue is young, cellular, and vascular. At that time the injured nerve was beginning its growth also. It was in granulation tissue, with many branching, irregularly coursing blood-vessels. These vessels directed its way, the new tendrils following the capillaries, there being no stronger force, such as the chemotropic influence of an opposite nerve stump, to attract it. Finally it may reach the old gap, but conditions now (at the end of weeks or months) are very different. Instead of a loose, vascular, cellular tissue, there is firm, dense, connective tissue. The nerve may perchance follow a vessel into this, and send a few young tendrils into the scar. The chances are that the wild, turning, twisting, spiral course it had already followed, for the most part under the influence of the capillary blood-vessels, will now be exaggerated. A bulb results.

It is not due to lack of ability to grow that the nerve bulb forms. It is rather due to its excessive hardihood. It coils when it cannot pass the block. Conditions made artificially by the surgeon at this stage are not to be compared with those existing at the beginning, when the granulation tissue was responsible for the tortuous path of the nerve, at the same time forming the fibrous scar. At the operation, months later, the young prolific nerves are, at the point of clean cut, ready to join their mates across the way. Any blood-vessels that form take the same direction.

In spite of all that must be said about the harm done by connective tissue in nerve work, this fact must not be overlooked, that nerves grow in scar tissue

(*Figs.* 434, 435). I have found them in 90 per cent of the so-called 'chéloïdes nerveuses.' True, they are not seen as a rule in great numbers, but they get there. At times I have found them in bundles, and more prolific than in the proximal end (*Figs.* 412, 427).

This scar tissue was sclerotic in only one of the cases described (Weir Mitchell refers to sclerosis of the connective tissue occurring rarely). It is usually wavy, vascular, cellular, connective tissue. Much of the density of the connective tissue (adhesions) about nerves is due to the great numbers of nerve tendrils mixed with the connective tissue. That massive nerve growth is firm has been demonstrated in the nerve bulbs.

The microscopic appearance of such masses of tissue is shown in *Figs.* 412, 422, 427, 433. Another section, a longitudinal one, through such a mass showed the fibrous part on the proximal side of the excised nerve, the *distal* portion being typical nerve callus.

Of course the severe trauma and infection are the usual basis for the scar formation. Tinel adds that "the hæmorrhagic infiltration determines 'à la longue' the fibrous infiltration of the nerve."

Adhesions.—The scar seen in adhesions is usually cellular, hæmorrhagic, vascular, and pigmented The nuclei are not compressed into flat spindles as in dense scar tissue, but are usually larger and vesicular. This may be said of most of the connective tissue that I have examined from about nerves.

Of the adhesions, 82 per cent contain nerves. These are usually seen as tendrils 1 to 3 μ in size, discrete in the connective tissue; but it is not uncommon to find bundles of nerves in the adhesions. Most frequently they occur in the form of small masses of interlacing fasciculi (nerve callus).

Tender Skin Scars.—Weir Mitchell examined painful skin scars "without being able to find the microscopic state of their nerve fibres." The neurokeratin stain demonstrates its value in the readiness with which these compressed nerves take the colour. I have invariably found both coned and varicose fibres in tender skin scars; and I have been just as unsuccessful in staining them in painless scars. The nerve bundles are sometimes seen also in the subcutaneous tissues.

Neuritis.—We have many specimens with small round cells infiltrating the endoneurium and perineurium. At times these cells are seen massed about blood-vessels. Foreign materials such as khaki, bone, hair, or gravel, may be surrounded by them. There is an admixture of epithelioid cells in these cases, and sometimes of plasma cells—evidence of chronic neuritis. If foreign bodies be present, giant cells surround them. As blood pigment is such a common finding in our material, we very often see it incorporated in phagocytes. Weir Mitchell writes that there is an extension of productive inflammation a great distance along the nerve. Tinel thinks that the hæmorrhagic exudate has a great deal to do with producing the neuritis type of trauma.

A type of chronic neuritis is seen in many of the nerve trunks we have examined; here small fasciculi of new tendrils follow the newly formed vessels in the young connective tissue. These fasciculi contain two to ten fibres, and interlace among the large nerves so as to form a network. This growth of young nerves, so commonly seen in the proximal segment, may be analogous to Kennedy's findings. He states that the nerve trunks in old amputated

limbs always contain an abnormal number of small nerve fibres in bundles. He takes them to be like the 'immature' fibres in the peripheral segment of a divided nerve.

Guinea-pig Transplants.—Phillipeaux and Vulpian, desiring to prove that nerves grow autogenically, transplanted normal lingual, hypoglossal median, and sciatic nerves beneath the skin of young animals. At the end of six months they found a new growth of young fibres, following degeneration of the original implant. Bethe and Kennedy likewise grew implanted nerves in animals. Ingebrigtsen was able to demonstrate the growth of nerves in Ringer solution after having left them *in loco* for five days following section.

The material I used for inoculation was excised from war injuries, and growth occurred at once in every instance. Even in the infected case, a prompt growth occurred. In most cases the growth was more mature in appearance than the control piece, for alongside the young branching varicose tendrils were found fasciculi and bundles of full-grown fibres.

We have an unusually readily growing material in nerves from war injuries, whether from proximal or distal end, completely or incompletely divided. Even where the control (*Figs.* 436, 437, 438, 439, 440, 441, 442) demonstrates few very fine tendrils, and these scattered throughout connective tissue, the resulting growth is in the shape of fasciculi and branching varicose tendrils of both young and fully-grown fibres. The fibres in the controls in no case are as well grown or as easily demonstrated as those of the transplant.

No growth can be demonstrated in the centre of the inoculated mass: it is seen at its periphery, and in the fat and granulations, skin, or muscle round about. Growth is usually seen along blood-vessels or in thrombosed veins. It is visible in the subcutaneous fat or connective tissue of the skin, and alongside the glands. Fasciculi are demonstrable crossing a space between granulations and skin. The conical formations and neurokeratin sheath of the axis-cylinders can be seen in our sections.

The normal varicose appearance of young actively growing nerves is proven beyond doubt. That nerves will grow under most unfavourable conditions was seen in a five-day growth, where the wounds were both open, and the guinea-pig died of infection. Some idea of the rate of growth may be obtained from these experiments. Skin controls made from the guinea-pig showed no nerves in the adjacent skin; but in sections from other guinea-pigs' skin I found a few bundles, but no young tendrils.

The neurokeratin stain is of value in determining the difference between a full grown and embryonal nerve. It demonstrates the nerve supply to the lymph gland and in the periglandular fat. Some of the fasciculi in the periglandular lymph sinuses and in the lymph spaces were possibly carried to the gland in the lymph stream and grew locally. They are seen with hair, degenerated muscle, and poorly-stained fragmenting pieces of nerve in some of the lymph spaces, and in periglandular fat among the vascular organizing connective tissue (*Fig.* 456). The nerves are seen as discrete young varicose tendrils branching about blood-vessels lining the lymph spaces. The adult fibres in these glands are medullated, they contain myelin globules, and stain with osmic acid (Schäfer says they are non-medullated).

The possibility of such a distant growth does not seem so remote when we note, in *Fig.* 446, a new growth of nerves in a piece of the original transplant which, carried from its original place of anchorage, grew at a point an inch away from its mate, which latter continued to grow independently near the scar. We might explain such a growth by the diapedesis or wandering of Schwann-sheath cells, as suggested by Kennedy, Kirk and Lewis, and Ingebrigtsen. Howell and Huber refer to the penetrating of scars by the protoplasmic masses of these neuroblastic cells—they could more readily find their way in the vital fluids of a guinea-pig.

In one guinea-pig we find nerves sending tendrils among the silk sutures used in closing the skin wound.

It is of more than ordinary significance that these transplants, taken from nerve callus and embryonal fibres growing in eight-months' scar tissue, should grow at once. Vulpian's implants from normal nerves degenerated before they began to grow—taking six months to get a start.

Nerve Stretching.—In order to determine what occurred to the nerves in war injuries where so much of the nerve was removed that stretching was necessary to get the ends together, I experimented on guinea-pigs' nerves, and include the result in this report.

One guinea-pig had its sciatic stretched, and seventeen days later examination demonstrated granulation tissue about the nerve. Blood pigment and phagocytes containing pigment granules were in and around the nerve. Varicose tendrils, 1 to 3 μ in size, were seen among the wider adult fibres, some of which were torn. There were many young varicose fibres in the granulation tissue surrounding the nerve.

S. Mayer has demonstrated that there is a continual degeneration and regeneration normally taking place in a nerve. We may, therefore, expect the neurilemma-sheath cells rapidly to repair damage done by stretching.

Weir Mitchell's experiments proved that a sciatic nerve continues to react to electrical stimuli until stretched three-quarters of an inch in three inches.

Langley quite recently writes: "New fibres can stand much strain. They may be used in a few weeks."

Bethe demonstrates that a stretched nerve unites as well as an unstretched one.

CONCLUSIONS.

There is a neurokeratin framework of the medullary sheath which envelops the axis cylinder as a sheath.

The carbol-fuchsin–osmic-acid–oil of cloves method is a specific stain for neurokeratin.

The Schmidt-Lantermann segments are normal physiological entities. Each segment is seen in adult nerves as a conical-shaped body attached by its base to the neurilemma sheath, and it envelops the axis cylinder for 10 to 20 μ. Extension and pressure of a nerve accentuates the appearance of the conical segments.

Adult and young nerves may be easily differentiated—the former showing conical segments, the latter appearing varicose and often taking a spiral

course. The young nerve is 1 to 3 μ in diameter, the adult measures 6 to 14 μ.

The so-called vacuoles are myelin globules surrounded by a fine neurokeratin film; they are seen in normal nerves of the human embryo and adult and in the guinea-pig.

Medullated nerve fibres occur normally in lymph glands of the guinea-pig.

War-injured nerves are ready to unite at both ends of the injury before the end of eight months. (The distal end has picked up some kind of central trophic influence in 86 per cent of our cases.)

The hardness of a nerve does not mean that it is fibrous—the nerve bulbs are very hard—three-fourths of each usually consists of young nerve fibres. These fibres contain axis cylinders, demonstrated by Bielschowsky's stain. They grow when transplanted into guinea-pigs, even quicker than the fibres of normal nerves.

The proximal and distal ends, the middle zone, and the adhesions contained nerves in the following proportions: proximal, 100 per cent; distal 86 per cent; middle, 90 per cent; adhesions, 82 per cent.

By the time the scar between the severed nerve ends has formed, the bulbous ends have already reached maturity.

The nerves in nerve bulbs are turned back on themselves. They multiply indefinitely. We have seen them actively forming seven years after operation. Some die as others form. They cause pain apparently by their excessive proliferation against resistance. Young nerves are found in most of the nerve trunks several centimetres proximal to the seat of injury (the point of resection). They are not confined to the line of the nerve. They course among the adult fibres singly and in fasciculi, often resembling nerve callus.

The grayish-pink pulpy (gelatinous) appearance of the cross-section of a nerve is due to vascular, protoplasmic, much nucleated material in the small nerve bundles—it means nerve regeneration. The denser grayish-white sections dotted with gray or grayish-pink points signify regeneration of young nerves; they have reached a fuller development than in the more pulpy (succulent) areas. All of this material grows rapidly in the guinea-pig transplant.

Constricting scar is particularly damaging when circular (around the nerve).

Nerves pulled aside by bone callus or adhesions always contain well-developed fibres.

Adhesions, middle-zone scar, and surrounding injured nerves are means of keeping the distal segment alive.

Some of the quickest good clinical results occurred in cases where only young nerves were found in the pathological material.

The old degenerated nerve fibres form the best conducting paths for the growth of young tendrils.

There is a strong attractive force (neurotropismus) exerted by one nerve on another growing nerve.

Nerves grow best from the proximal end.

Nerves grow well in granulation tissue. Blood-vessels act as a scaffolding along which and within which nerves grow; in the early stages of nerve injury they tend to misguide a nerve from a straight path.

Nerves grow well in fascia lata, and in fact better than in muscle; but Cargile membrane is impervious to them.

Nerve tendrils grow about foreign material, such as khaki, hair, and sutures.

The neurilemma-sheath cells proliferate greatly in and around the old nerve fibres and at a distance, giving rise to new fibres. The sheath cells find their way into neighbouring and distant tissues. The nuclei are seen in great numbers before the young fibres sprout, and disappear as these tendrils appear.

Nerves which reach the scar tend to penetrate it.

The connective-tissue formation between nerve ends, around them, and within them, is usually wavy and vascular, often cellular, scarcely ever sclerotic.

Nerves are invariably seen in painful scars.

The subcutaneous implants into guinea-pigs of pieces from the proximal and distal ends and from the bulbs on the sides and ends of injured nerves, grow at once. There is no primary degeneration such as occurs when normal adult nerves are transplanted.

The implanted nerves grow at various points separated from the original seat of inoculation, suggesting a metastasis by cells of the neurilemma sheath.

The transplanted nerve grows in lymph glands when carried to them in the lymph stream as neurilemma-sheath cells.

Transplanted nerves grow even when infected.

The transplant growth in granulation tissue finds its way to distant nerves.

A stretched nerve shows active new growth of young tendrils.

I wish to thank Colonel Sir Robert Jones for giving me the opportunity to do this work. To Professor Ernest Glynn I am much indebted for suggestions, and for his kindness in giving me every facility at the Thomson Yates Pathological Laboratory to carry on these investigations.

The execution of the photomicrographs is the war contribution of Mr. R. Shepherd, for which we are most grateful.

[*Illustrations of this article will be found on pp. 549–557.*]

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HISTOLOGICAL APPEARANCES.

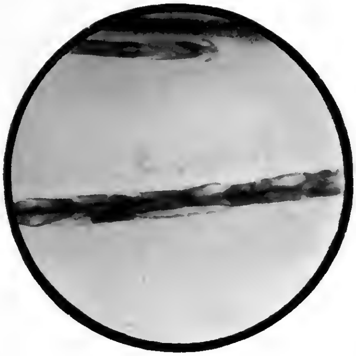

FIG. 405. (× 480.)

FIG. 405.—Nerve from an amputation stump, stretched at time of excision. Nerve entering stump bulb. Invaginated (intussuscepted) appearance at location of Schmidt's incisures. Axis cylinder sheath can be seen.

FIG. 406.—Stretched nerve from stump. Cones and globules of myelin outlined by neurokeratin framework. Axis cylinder sheath and attachment of base of cones at neurilemma sheath seen as circles. The light area between the inner circle (axis cylinder sheath) and outer circle (base of cone attached to the sheath of Schwann) is the medullary sheath.

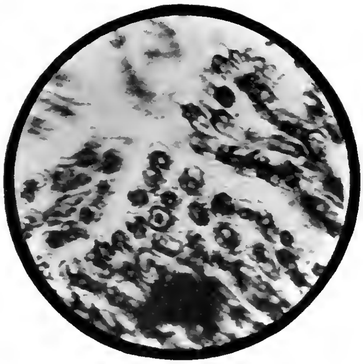

FIG. 406. (× 480.)

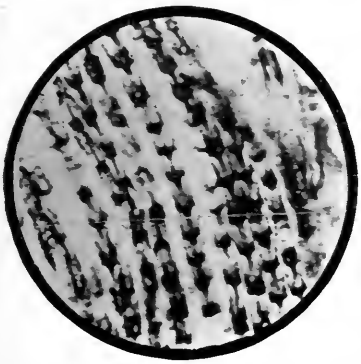

FIG. 407. (× 480.)

FIG. 407.—Same as 406, cut less obliquely. Regular arrangement of cones 30 μ long. Axis cylinder sheath demonstrated. Myelin globules ('vacuoles') seen enveloped by neurokeratin framework.

FIG. 408.—Side bulb on ulnar nerve. Ulnar was grafted with rabbit's nerve 7 years ago. Cones and globules. Several 3 μ nerves among adult (12 μ) nerves faintly outlined. The globules of myelin are seen outlined by neurokeratin in the fibres at the margin of the photo; these were cut near the sheath of the ulnar.

FIG. 408. (× 480.)

FIG. 409. (× 480.)

FIG. 409.—Same as 408. Globules of myelin not taking the stain. Neurokeratin deeply stained.

FIG. 410.—Sciatic nerve regenerating: proximal end, 2 months; cut 25 μ thick. Numerous young tendrils in swollen protoplasmic material ('axial strands') in old fibres. A few nuclei faintly outlined seen in surrounding cellular connective tissue. (Stained by Van Gieson, the circles from which these tendrils project were seen to be full of nuclei in swollen protoplasm.)

FIG. 410. (× 480.)

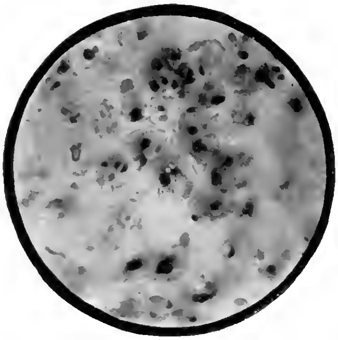

FIG. 411. (× 480.)

FIG. 411.—Same as 410, lower down the section. Some balls of degenerated myelin (stained black) alongside young nerves. A few faintly outlined nuclei. The smaller dark objects are nerves—they were stained mauve.

FIG. 412.—Section at middle of excised nerve. Young nerves (2 to 3 μ) outlined in protoplasm of old fibres. Black border of fibre has a notched appearance, due to the closely aggregated young nerves. The very faint splotches throughout the section are nuclei; they do not take the mauve colour, so are photographed with difficulty.

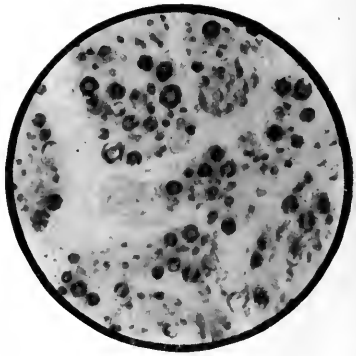

FIG. 412. (× 480.)

FIG. 413. (× 90.)

FIG. 413.—Numerous young varicose spiral fibres in old fibres of nerve bundle. Proximal end. Four months' growth. There are 5 to 10 new tendrils in each original nerve fibre.

FIG. 414.—New growth in old fibres and in thickened perineurium of distal segment of excised nerve. No adult fibres with cone formation were seen under higher magnification.

FIG. 414 (× 90.)

FIG. 415. (× 240.)

FIG. 415.—Many good adult nerves (7 to 10 μ) with cones in old trunk of distal end of completely divided nerve. After 6 months. A few 3 μ nerves and some non-staining old fibres and connective tissue are seen.

FIG. 416.—Tendrils and adult nerves in old bundle in peripheral segment of excised nerve.

FIG. 416. (× 240.)

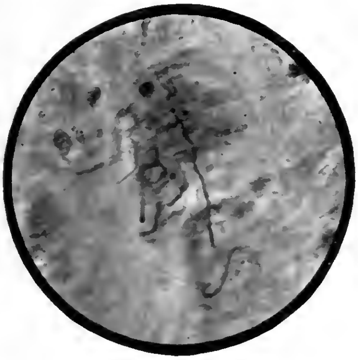

Fig. 417. (× 480.)

Fig. 417.—Axis cylinders stained by Bielschowsky's method in peripheral segment of excised nerve.

Fig. 418.—Foreign body with a branching nerve tendril close to it. Other tendrils, near by, could not be brought into the same focus with the one photographed.

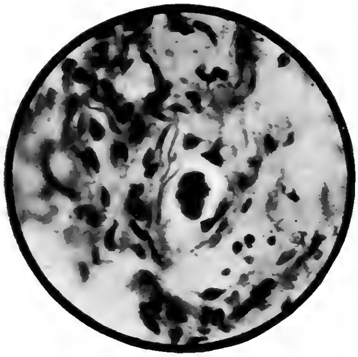

Fig. 418. (× 480.)

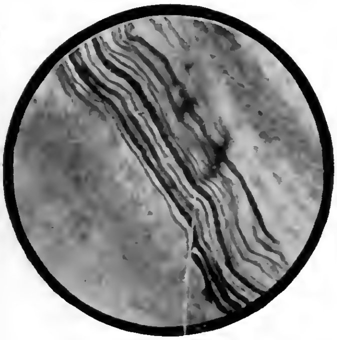

Fig. 419. (× 240.)

Fig. 419.—Bundle of adult and young fibres in lumen of thrombosed vessel. The nuclei in the vessel walls are faintly outlined.

Fig. 420.—Same as *Fig.* 419. Young varicose fibres (2 to 4μ) growing in walls of vein. They are spiral in form and run in various directions.

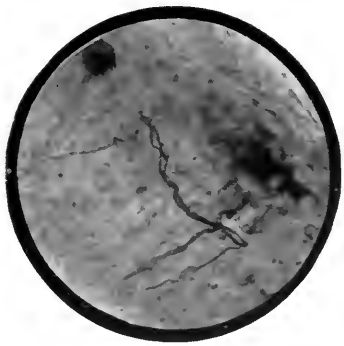

Fig. 420. (× 240.)

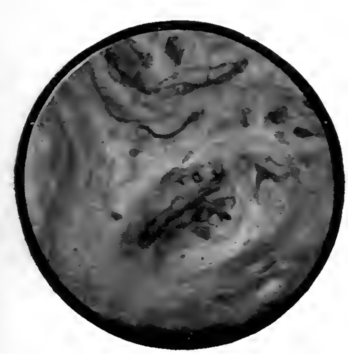

Fig. 421. (× 480.)

Fig. 421.—Young nerve fibres in vein. Section made at point of branching of vein. There is a fasciculus in the centre. Several varicose tendrils are seen in the branch.

Fig. 422.—Cross section of proximal end of excised nerve. Endoneurium increased. Higher magnification demonstrates young tendrils in the old fibres. Cell increase present. Macroscopically it was pinkish-gray, gelatinous, and divided into lobules (funiculi).

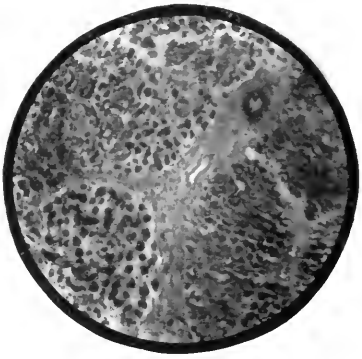

Fig. 422. (× 90.)

FIG. 423. (× 90.)

FIG. 423.—Young nerves in distal segment of excised nerve, intertwining as in nerve callus. Some tendrils discrete in the thickened connective tissue. Fasciculi are seen cut longitudinally and transversely.

FIG. 424. — Fasciculi of young fibres in vascular connective tissue alongside a nerve bundle in adhesions. The black mass is the bundle—individual nerves may be traced.

FIG. 424. (× 90.)

FIG. 425. (× 90.)

FIG. 425.—Bundles of full-grown coned fibres in proximal end. Much loose connective tissue, infiltrated with blood, surrounds the bundles.

FIG. 426.—Proximal end. Many good fully-formed fibres in old degenerated bundle (2¼ years). Connective tissue has taken the place of many fibres, and is increased in the endo- and perineurium. (Magnification × 400 demonstrates cones in some of the fibres.)

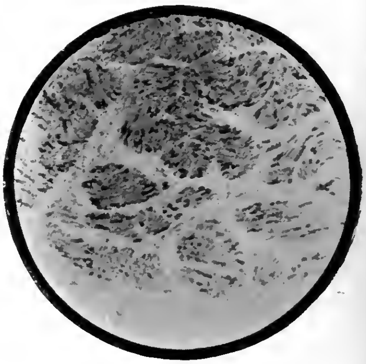

FIG. 426. (× 90.)

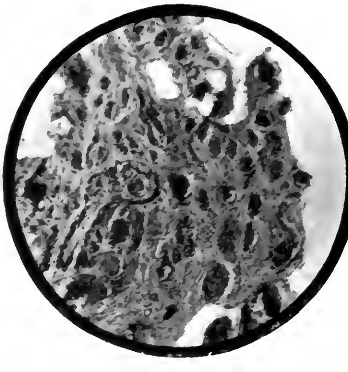

FIG. 427. (× 90.)

FIG. 427.—Excised nerve; 6 cm. removed; section is from the firm fibrous portion near the middle. Fasciculi of good adult fibres. The fasciculi are more definitely circumscribed than usual.

FIG. 428.—Very much like *Fig.* 427. Interlacing fasciculi like those seen in nerve callus. The fibres are all young. This kind of tissue is very common in the proximal segment.

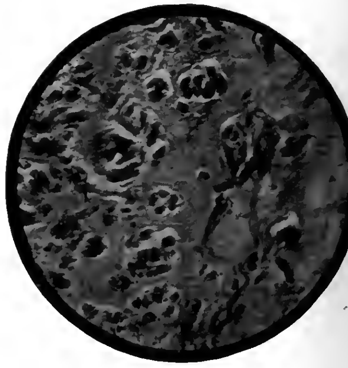

FIG. 428.

Fig. 429. (× 90.)

Fig. 429.—Interlacing fasciculi of young nerves in loose hæmorrhagic connective tissue. Taken from adhesions around the nerve.

Fig. 430. — Nerve callus from bulb of posterior tibial bound in scar tissue to bone. Very little connective tissue among fasciculi. These measure 10 to 30μ and contain tendrils of 1 to 3μ. Van Gieson's stain shows numerous nuclei—elongated and oval-shaped.

Fig. 430. (90.)

Fig. 431. (× 90.)

Fig. 431.—From adhesions to the nerve. Nerve callus makes up the mass of the adhesions. Interlacing fasciculi of young nerves. Little connective tissue.

Fig. 432.—Nerve callus of bulbous end of nerve. Young varicose tendrils (1 to 3μ) in fasciculi. Connective tissue unstained. Nuclei faintly outlined as blurred masses alongside the tendrils.

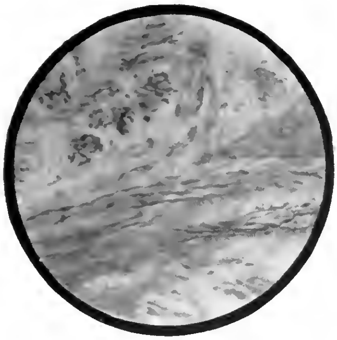

Fig. 432. (240.)

Fig. 433. (× 90.)

Fig. 433. — Nerve callus from bulb. Interlacing fasciculi, more nerve than connective tissue.

Fig. 434.—Painful skin scar at end of stump. Coiled fibre in connective tissue, following a blood-vessel. Only one fibre in this fasciculus could be focussed properly in taking the photograph. Specimen gave positive result with Bielschowsky's axis cylinder stain.

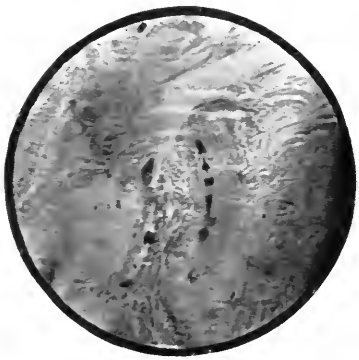

Fig. 434. (× 480.)

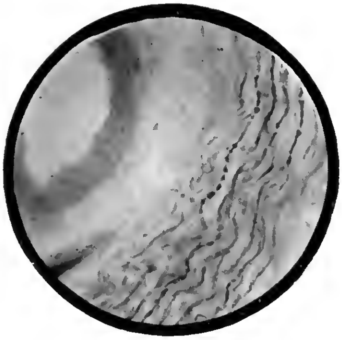

FIG. 435. (× 240.)

FIG. 435.—Painful skin scar. A fasciculus of newly-formed nerves in dense fibrous tissue, blood-vessel alongside. Coned (8μ) and varicose (3μ) fibres seen in the same fasciculus.

FIG. 436.—Distal end of excised internal cutaneous nerve. A guinea-pig was inoculated with a piece from this (cf. *Figs.* 443, 444, 445). A few young varicose tendrils in vascular cellular connective tissue. (Many elongated blunt neurilemma sheath nuclei were seen in this section.)

FIG. 436. (× 480.)

FIG. 437. (× 90.)

FIG. 437.—Proximal end of excised internal cutaneous nerve. A guinea-pig was inoculated with a piece from this 'control' (cf. *Figs.* 446, 447). A few good adult coned fibres among proliferating nuclei of the neurilemma sheath. (This is frequently mistaken for connective tissue.)

FIG. 438.—Distal end of ulnar nerve. A piece from this was implanted into a guinea-pig (cf. *Figs.* 448, 449). Discrete young varicose tendrils (black) in loose cellular connective tissue.

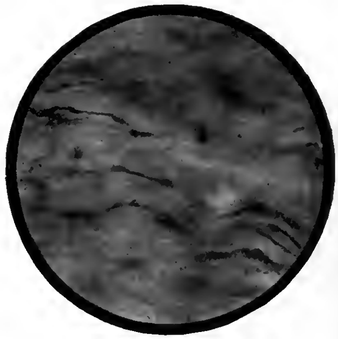

FIG. 438. (× 480.)

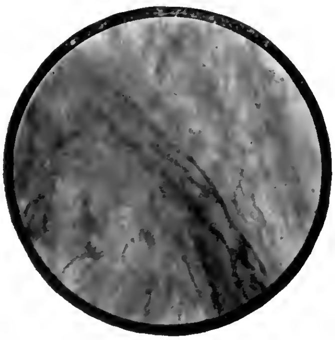

FIG. 439. (× 480.)

FIG. 439.—Distal end of ulnar from which a piece was transplanted into a guinea-pig (cf. *Figs.* 450, 451, 452, 453). Varicose young fibres (3μ) in connective tissue.

FIG. 440.—Distal end of ulnar. Implant from this was placed in subcutaneous tissue of guinea-pig (cf. *Figs.* 454, 455, 456, 457). A few discrete young varicose tendrils in cellular connective tissue. (Several fibres are in the field, but only one at a time could be well focussed.)

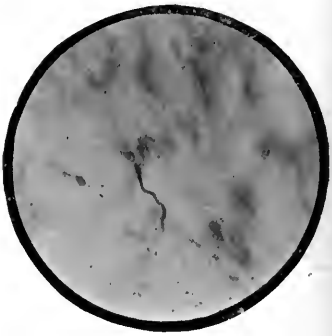

FIG. 440. (× 480.)

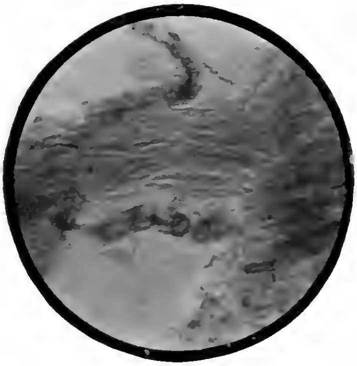

FIG. 441. (× 480.)

FIG. 441.—Nerve from $3\frac{1}{2}$-months' fœtus, showing cones and globules.

FIG. 442.—From second bulb of proximal segment of ulnar nerve. A piece was implanted into a guinea-pig (cf. *Fig.* 458). There are a number of tendrils (1 to 2 μ) in a bundle, running parallel in dense connective tissue. There was great round-cell infiltration and dense connective-tissue formation, and little evidence of new nerve formation elsewhere.

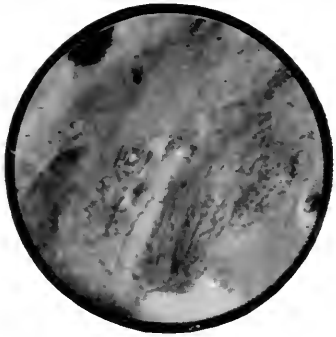

FIG. 442. (× 90.)

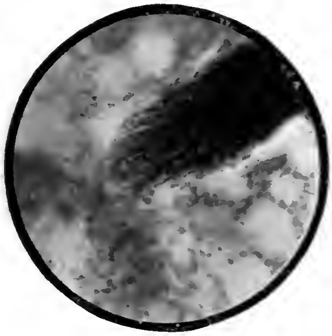

FIG. 443. (× 240.)

FIG. 443.—Eight-day growth in guinea-pig transplant. Fasciculus of young and full-grown fibres in granulation tissue in the subcutaneous fat. (*Fig.* 436 represents the control piece.)

FIG. 444.—Eight-day growth in guinea-pig transplant. Discrete young fibres in subcutaneous connective tissue. Nerve appears black, nuclei blurred.

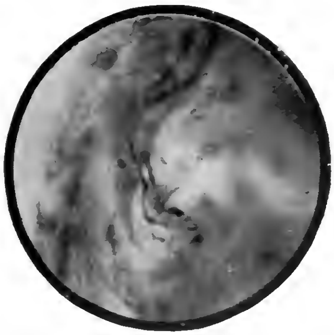

FIG. 444. (480.)

FIG. 445. (× 240.)

FIG. 445.—Eight-day growth in guinea-pig transplant. Degenerated fasciculus in granulations. Cones broken. Black fragments of myelin displaced.

FIG. 446.—Guinea-pig transplant (8 days). Cellular granulation tissue. The piece was separated by an inch from growth at scar. Both varicose (young) and coned (full-grown) fibres are seen. (*Fig.* 437 shows the control piece from which this grew.

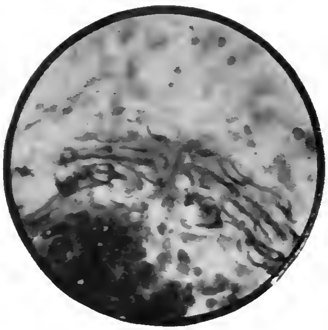

FIG. 446. (× 480.

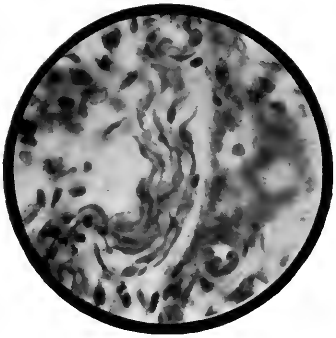

FIG. 447. (480.)

FIG. 447.—Growth in guinea-pig (8 days). Fasciculus of young fibres in vascular granulations in subcutaneous connective tissue. Nuclei proliferating and seen in close relation to nerve tendrils.

FIG. 448.—Growth in guinea-pig (13 days). Fasciculus in granulations in subcutaneous fat. Young and full-grown nerve fibres. Nerve was cut as it changed its direction.

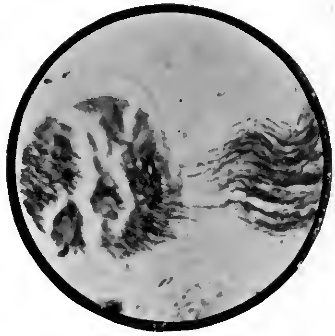

FIG. 448. (× 240.)

FIG. 449. (× 480.)

FIG. 449.—Growth in guinea-pig (13 days). Fasciculi from which varicose branching tendrils are spreading in the guinea-pig's muscle. Note the bulbous ends of the growing young nerves. (The spiral form makes it impossible to show the entire length of the tendril in the picture.) Nerves appear black.

FIG. 450.—Growth in guinea-pig (35 days). Single tendrils in granulations in subcutaneous tissue, appearing varicose and spiral.

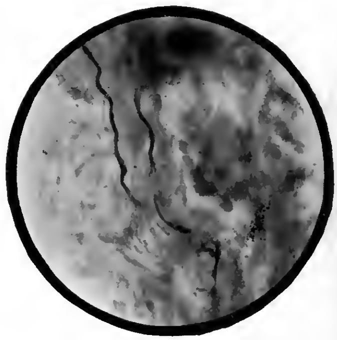

FIG. 450. (× 480.)

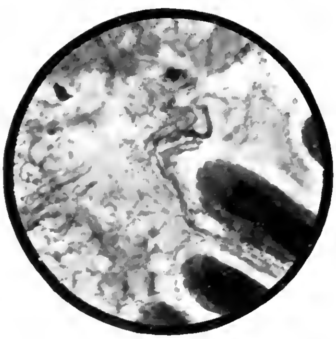

FIG. 451. (× 90.)

FIG. 451.—Growth in guinea-pig (35 days). Young varicose fibres in spiral form growing about hair sacs.

FIG. 452.—Growth in guinea-pig (35 days). Transplant made in thigh. Young spiral tendrils following a blood-vessel in granulation tissue in lymph sinus of lymph gland in groin. Some may be faintly seen out of focus. Lymph follicles alongside.

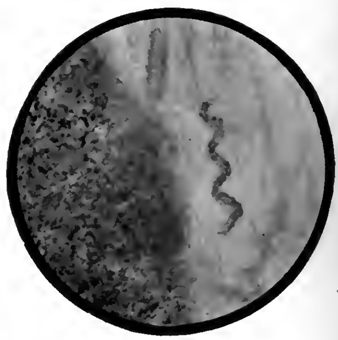

FIG. 452. (× 90.)

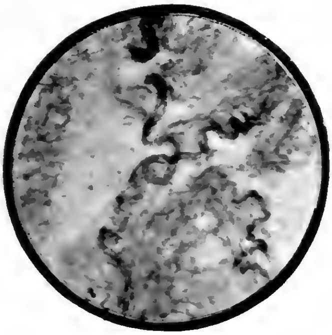

FIG. 453. (× 90.)

FIG. 453.—Growth in guinea-pig transplant (35 days). Young spirals in granulations in subcutaneous fat. Several varicose tendrils in each fasciculus. They follow faintly-outlined blood-vessels.

FIG. 454.—Transplant in guinea-pig (18 days). Fasciculus in muscle. Full-grown (8μ) fibres.

FIG. 454. (× 90.)

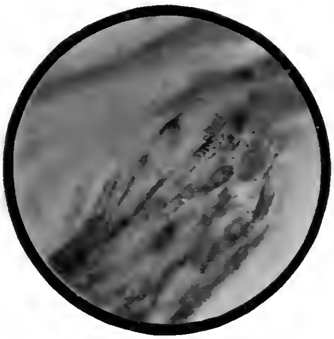

FIG. 455. (× 480.)

FIG. 455.—Growth in guinea-pig transplant (18 days). Fasciculus of full-grown fibres (myelin globules noted) in subcutaneous tissue. Cones and axis cylinder sheath faintly outlined.

FIG. 456.—Growth in guinea-pig transplant (38 days). Lymph-gland sinus, containing granulations, nerve fasciculi, and discrete tendrils. Fasciculi are densely stained (black). Young spiral tendrils in narrow fasciculus at edge of granulations.

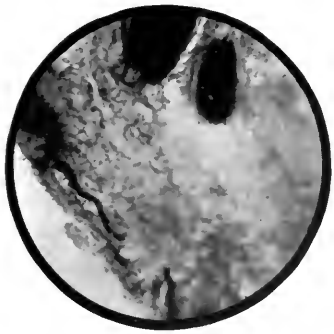

FIG. 456. (× 90.)

FIG. 457. (× 240.)

FIG. 457.—Growth in guinea-pig (38 days). Spirals of young varicose tendrils in granulations among muscle fibres.

FIG. 458.—Growth in guinea-pig transplant (5 days). Fasciculus in granulations about piece near groin separated from original seat of inoculation. Fasciculus in granulation tissue alongside degenerating inoculated mass.

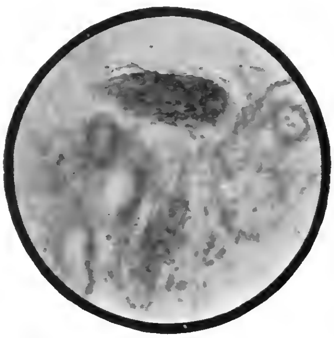

FIG. 458

A STUDY OF A SERIES OF WOUNDS INVOLVING THE BRAIN AND ITS ENVELOPING STRUCTURES.

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SUMMARY OF CONTENTS.

FOREWORD.

WHEN novel surgical experiences, no matter how numerous, are crowded into the period of a few weeks, it is unsafe to draw too many deductions therefrom. The past three years have shown how often favourable opinions which were not based on the study of end-results have had to be retracted—how often unfavourable opinions, based on improperly conducted operations, have had to give way to the results of those better planned. One needs but recall the story of many of the antiseptics, of abdominal operations, of experiences with wounds of the thorax and joints, of primary and secondary suture of wounds. Hence, what may be said in these pages is said with all reservation and with full admission of a brief apprenticeship.

After these three years there is possibly less unanimity of opinion as regards the principles of treatment of cranio-cerebral injuries than of any other type of wounds. Reasons are not far to seek. Anything classified as neurological is looked upon by many of us as baffling and difficult, and a feeling prevails that the ultimate functional results after recovery from serious cranial injuries are, to say the least, forlorn. Few medical officers had received training in the surgery of the central nervous system before the

war; no organized instruction has been given in the subject since; and the tools provided for the work have been inadequate and antiquated. Furthermore, diverse, and at times confusing, opinions have been expressed regarding the treatment of these conditions, without accompanying mortality figures and illustrative clinical records to serve for others as a basis for comparison. For without definite statistics, accompanied by case-histories, the surgeon cannot tell what have been the surgical results in the past of methods different from his own: without them he cannot tell whether his own percentage of recoveries is improving as time goes on.

With the object therefore of placing on record the account of a consecutive series of surgically-treated cases, with results both good and bad, this paper has been put together; and such opinions as are expressed are given with full appreciation of the sentiment in the opening paragraph.

Material.—During the three months from July 23 to Oct. 31, 1917, a series of 250 examples of injury to the head came under the care of a 'surgical team,' of which the writer was a member, at a casualty clearing station in which all so-called head cases for a given army front were congregated.

As recorded elsewhere,* 219 of these cases, which were in large part referred to us or selected by us as being cases of major gravity, were operated upon, disclosing wounds of the following types. There were 22 cases with scalp wounds (10·1 per cent), 54 with wounds involving cranium as well as scalp, but with intact dura (24·6 per cent), 133 with wounds with dural penetration (60·7 per cent), and 10 (4·5 per cent) massive or bursting fractures with serious intercranial complications, though usually with intact scalp and dura. The 31 additional cases comprised 20 whose condition on admission precluded operation, and 11 whose injuries were allowed to pursue their course without actual operation.

In the above report on the 219 cases, attention was called to a method of treating penetrating wounds, its essential features being the removal *en bloc* of the area of bony involvement, the withdrawal by suction through a soft catheter of the devitalized cerebral tissue lining the track, without enlargement of the dural opening, and the extraction of bone fragments with the least possible increase in the trauma already produced. A progressive improvement in the percentage of recoveries was attributed in large part to the adoption of these methods, for the mortality of the 133 cases with dural penetration had been lowered from 54·5 per cent for the first 44, to 40·9 per cent for the second 44, and to 28·8 per cent for the third 45 cases.

These figures, it should be pointed out, represent the combined results of a single team, the junior members of which were occasionally changed, and though all of us operated from time to time, the writer is responsible for the majority of the cases. No cases have been eliminated from the series for any cause, even when death has been obviously due to some complicating condition apart from the injury to the head.

At the outset we had no settled programme, except to limit ourselves, so far as circumstances permitted, to the cases with dural penetration, the post-operative mortality of which, from hearsay, we were led to believe was

* "Notes on Penetrating Wounds of the Brain," *Brit. Med. Jour.* 1918, Feb. 23.

something over 50 per cent. There were no prescribed rules of procedure, aside from the regulation that after operation cases should be retained for ten days, as transportation was supposed to favour the post-operative complications so frequently seen. Unoperated cases, on the other hand, with the exception of those with a rapid pulse, could if necessary be forwarded to the base; indeed, there was some contention that all cases should be sent to base hospitals for their operation, as there was no harm and possibly some advantage in the delay.

Our early operations, under a general anæsthetic, with flap exposures and imperfect cleansing of the track, did very badly, and the mortality, usually due to infection, ranged between 50 and 60 per cent. The usual line of treatment and sequel may be told by a case report.

Case 1.—Rfm. J. Y. (Serial No. 7). **Left parietal penetrating wound. Incomplete operation: bone fragments and small projectile retained. Abscess; fungus cerebri. Death: encephalitis, 12th day.**

Admission to C.C.S. July 29, 1917, 9 a.m.—Wounded about eight hours previously; wearing helmet. Stunned, but no loss of consciousness. Headache.

General Condition.—Good; fully conscious; warm; pulse 96.

Wounds.—Two small scalp wounds of left occiput; a small penetrating wound just below left parietal eminence. *X* rays show small fracture of left parietal, with metal fragment 10 cm. from plate near mid-plane of skull.

Neurological Findings.—Paralysis and spasticity of right arm and leg; weakness of right face. Also lowered sensory perception to pain. Slight paraphasia. Deep reflexes exaggerated in right arm and leg, without clonus; no plantar response. Possibly a right homonymous (upper quadrant) hemianopsia.

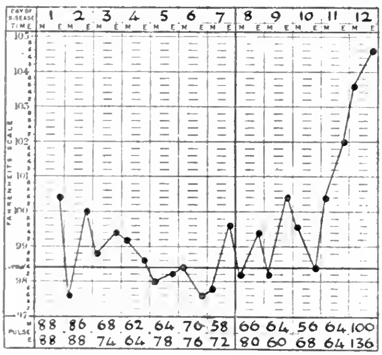


FIG. 459.—*Case* 1. Showing temperature rise after ten-day interval.

Operation, 10 a.m. (after 9 hours).—Ether. Flap reflected, with excision of scalp wound; enlargement by rongeurs of small opening in skull, disclosing a cerebral protrusion; circular resection, with enlargement of dural opening; removal by palpation and irrigation of a few superficial bone fragments from track in brain. Closure with lateral rubber-tissue wick drains. Multiple scalp wounds of occiput repaired. A rapidly conducted procedure.

Post-operative Course.—Incontinent, restless, and somewhat irrational for two days; required morphia. Superficial infection of wound, which was opened and Carrelized. Subsequently, general condition improved, though the neurological findings were unaltered. Slight rise in temperature on seventh day; some focal seizures in face. Small fungus cerebri, with discharge of two bone fragments and some disorganized brain tissue. On ninth day further discharge of bone fragments. Slowing of pulse. On eleventh and twelfth days rise of temperature to 105° (*Fig.* 459), with stupor. Death, Aug. 9, 11 p.m.

Autopsy.—Brain shows no evidences of meningitis. A fungus the size of a pigeon's egg overlies the left angular gyrus. The track of the projectile is surrounded by softened and septic brain tissue containing spicules of bone. It passes upward and slightly forward through the parietal lobe, internal capsule, and falx, and enters the right hemisphere, where lies a minute shell-fragment (*Fig* 460) surrounded by an abscess 3 cm. in diameter unconnected with the very septic track. The 0·35-grm. missile shows a burnished surface, evidently from helmet perforation.

This, in short, was a type of case with sequence all too common—an incomplete removal of infected bone fragments, resulting in a septic track. a spreading encephalitis, a broken-down wound with fungus, and death without meningitis. Meanwhile the small foreign body was making its own separate nest of trouble in the opposite hemisphere. The terminal upset, with rise in temperature on the eleventh and twelfth days, would naturally have been attributed to his transportation had he been evacuated the day before.

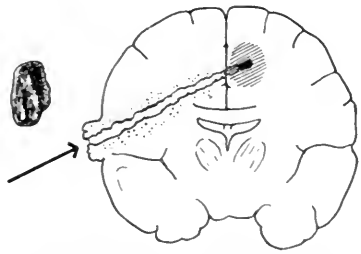


Fig. 460.—*Case* 1. Projectile (natural size), and course through brain.

The repetition of a few experiences of this kind led in time to a complete change in technique, after the manner described elsewhere,* with painstaking toilette of the track carried out without haste under a local anæsthetic.

CLASSIFICATION OF HEAD INJURIES.

For many people the term gunshot wound of the head brings up a picture of the cranial injury alone. It is the fractured skull which is exhibited in our museums, not the damaged brain. The various forms of fracture are thus familiar to all, and the teachings of operative surgery explain the use of the trephine and the manner of dealing with the fracture, scant attention being paid to the neurological lesion underneath.

Fractures of the skull have been most variously classified—according to their anatomical situation (frontal, temporal, basal, etc.), according to the character of the bony lesion (fissured, depressed, penetrating, etc.), according to the mechanism of their production (by bending, bursting, etc.). Gunshot wounds are usually placed in a separate category, which again has been made to undergo further subdivisions according to the nature of the projectile, its size or course, its lodgement or otherwise, the region of impact, the extent of radiation of the fissures, and many other qualities.

But, to the victim of the injury, what has happened to the skull is of far less moment than what has happened to the brain, and this has been given less study. Indeed, since the time of Hippocrates we have been warned against carrying our investigations beneath the dura. This, however, we are often compelled to do, and in so many cases has the membrane been opened for us by the missile, that a subdivision of projectile wounds of the head into those with and those without dural penetration has become a fairly common one. We thus have already had forced upon us some recognition of the intracranial injury in our efforts suitably to classify wounds of the head.

In the present paper the attempt will be made to carry the matter a little further, and to grade the cases in accordance with the seriousness of the condition so far as the cranial contents are concerned. The gradations

* *Brit. Med. Jour.* 1918, Feb. 23.

are tentative, and have been made as comprehensive and as few in number as possible; also with the least possible dislocation of our old formulas regarding the cranial injury. The scale is one of ascending severity, and as will be seen, the surgical mortality for each successive group, with a single exception, is higher than the one before. There are doubtless imperfections in the scheme, and other subdivisions may be better, but it is thrown out merely as a temporary working basis on which cases may be recorded for purposes of comparison without too great elaboration.

HEAD INJURIES GRADED ACCORDING TO THEIR SEVERITY.

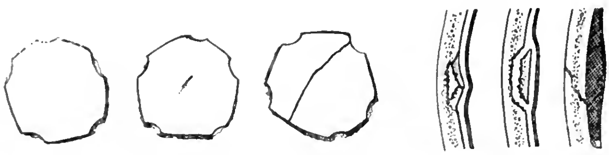
With mortality figures for each group under the condition recorded.

Grade I.—WOUNDS OF THE SCALP, WITH INTACT CRANIUM AND DURA.

Occasional underlying cerebral contusion. 22 cases: 1 death (4·5 %).

Grade II.—WOUNDS PRODUCING LOCAL FRACTURES OF VARIABLE TYPES, WITH THE DURA INTACT.

A



Type A. — Without depression of external table.

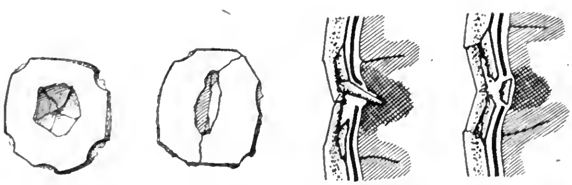
Type B.—With depression of external table.

B

Local contusions of brain or extradural extravasation fairly common.

54 cases: 5 deaths (9·2 %).

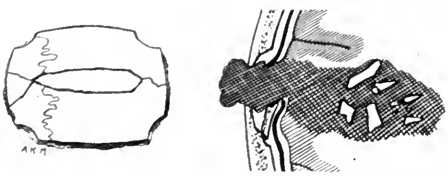
Grade III.—LOCAL DEPRESSED FRACTURES OF VARIOUS TYPES, WITH THE DURA PUNCTURED.



Local contusions inevitable, usually with positive neurological signs; cerebral extrusion uncommon.

18 cases: 2 deaths (11·8 %).

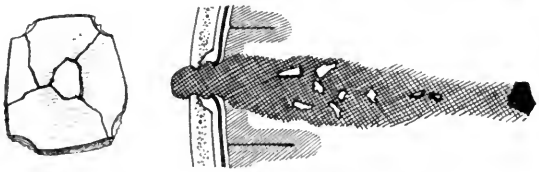
Grade IV.—WOUNDS, USUALLY OF GUTTER TYPE, WITH DETACHED BONE FRAGMENTS DRIVEN INTO BRAIN.



Local contusion severe, and extrusion of brain almost inevitable. Fungus cerebri, encephalitis, etc., common sequels.

25 cases: 6 deaths (24 %).

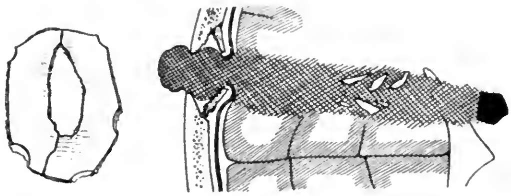
Grade V.—Wounds of Penetrating Type, with Lodgement both of Projectile and Bone Fragments.



Brain often extruding: contusion along track. Symptoms depend on size and course of missile. Common sequels: early compression, late abscess.

41 cases: 15 deaths (36·6 %).

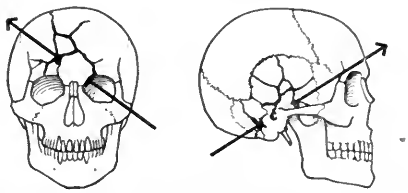
Grade VI.—Wounds with Ventricles Penetrated or Traversed (*A*) By Bone Fragments, (*B*) By Projectile.



Cerebral lesion as in *Grades IV* and *V*, with cerebrospinal fluid escape. Hæmorrhage into, or subsequent infection of ventricle common.

Type A.—
14 cases: 6 deaths (42·8 %).
Type B.—
16 cases: 16 deaths (100 %).

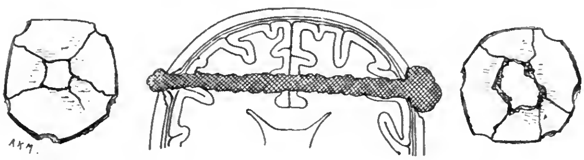
Grade VII.—Wounds of Cranio-cerebral Type Involving (*A*) Orbital-nasal, (*B*) Auro-petrosal Region.



Brain commonly exposed and extruding; radiating fractures; nasal or petrosal cavities opened; meningitis common.

15 cases: 11 deaths (73·3 %).

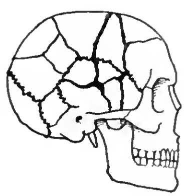
Grade VIII.—Wounds with Cranio-cerebral Perforation.



Extensive cranial and cerebral damage common. Death usually due to intracranial hæmorrhage and compression.

5 cases: 4 deaths (80 %).

Grade IX.—Cranio-cerebral Injuries with Massive Fracture of Skull.



Widespread cerebral contusion. Compression phenomena common.

10 cases: 5 deaths (50 %).

The present is no time to become deeply involved in new classifications. Hence, in the foregoing scheme, as few new elements as possible have been introduced, chiefly those relating to the important matter of intracranial infection—dural penetration, cerebral extrusion, ventricular penetration, and opened portals of infection through nose and inner ear. Other elements which greatly modify the wounded man's chance of recovery—the degree of shock and exposure, the establishment of infection before admission in cases lying out, the lapse of time between the injury and the operation, the multiplicity of cranial wounds, complicating conditions such as concomitant wounds elsewhere or gas poisoning—all these and many more modifying elements must be omitted, lest there be too great confusion.

Group I.—WOUNDS OF THE SCALP.

Of all superficial wounds, simple scalp wounds are possibly the most susceptible to primary closure, with early return of the patient to his duties. Hence the inclusion of scalp wounds in a discussion of wounds of the head might seem unnecessary, were it not for the tendency to underestimate them, and to forget that even among the walking wounded every scalp wound must be regarded as a potential penetrating lesion of the brain. For even with the help of radiography, it may be impossible to foretell what investigation will reveal in the way of an underlying lesion.

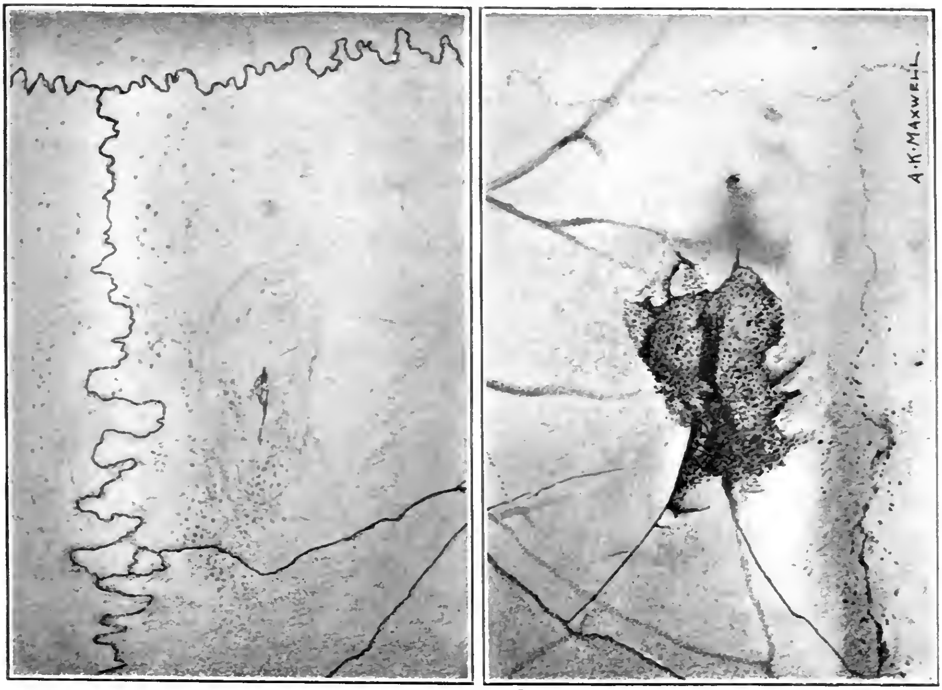
On the other hand, we may overestimate the scalp wound. In the series of 22 verified cases, there were 16 in which a cranial or cranio-cerebral injury was anticipated, either because of the patient's neurological symptoms, or because of the appearance of the external wound itself. For example, the field medical cards of three of the patients recorded the presence of a hernia cerebri, which on investigation proved to be merely a pulsating clot filling a superficial gutter-wound of the temporal muscle.

However, though many scalp wounds which appear serious prove to be trifling, more which appear trifling prove to be serious. Two cases of the series were prepared for operation owing to the presence of a large gutter wound of the scalp, with the expectation of finding a fracture; and not until the head had been shaved, was a small wound disclosed elsewhere which was actually a wound of penetration, the obvious wound proving on investigation to be limited to the scalp alone. All surgeons working in a forward area have had similar experiences. Even the x rays may not help greatly, for they often fail, on a lateral view, to disclose slightly depressed fractures; while on the other hand, irregularities of the skull, particularly those along the mid-vertex, may be mistaken for fractures.

Scalp wounds, in fact, cannot be glossed over in making a report on wounds of the head. The statistical study of all the cases with a diagnosis of gunshot wounds of the head or scalp, during a two weeks' period of military activity with a large number of wounded, disclosed the fact that 85 per cent of all the cases were immediately evacuated after a mere change of dressing—practically all of them walking cases, the wounds supposedly being scalp wounds. Many severe, even penetrating, wounds must have been included. It is of course a physical impossibility to examine neurologically, to submit

to an x-ray exposure, and to operate upon all cases in times of pressure: and whether the simple or the more severe wounds should be given operative attention at such a time is a matter for a military rather than a medical decision.

Twenty-two cases in the series were classified as scalp wounds on the basis of the operative findings, for the outer skull proved to be intact, and none of them were trephined. In 12 of them (54·5 per cent) there were complicating wounds elsewhere of greater or less severity. There was one fatality. This man's story may be cited at the outset, to illustrate the difficulties of any classification and the admitted imperfections of the one adopted.



Figs. 461, 462.—*Case* 3.—Showing external table practically intact except for distant fissures; internal table with extensive defect (cf. *Fig.* 463).

Case 2.—Pte. T. L. (Serial No. 27). **Scalp wound, with fatality from contusion of hind-brain.**

Admitted Aug. 1, 1917, 9.30 p.m.—Unconscious. Pulse 90, irregular. Respiration shallow, rhythmic, gurgling. Multiple wounds of arm; scalp wound of mid-vertex. Exaggerated deep reflexes.

Aug. 2, 12.10 a.m.—Lumbar puncture: 50 c.c. very bloody cerebrospinal fluid. 2 a.m.—Operative repair of multiple wounds. Consciousness never regained. Cheyne-Stokes' respiration. Death in 48 hours.

Autopsy.—No cranial injury; outer aspect of brain normal, but there were clots and bloody fluid in the cerebellar fossa, and sections disclosed a small hæmorrhage in the cerebellar vermis.

The clinical diagnosis lay between fracture of the base and a parasinoidal contusion, neither of which was found. The case remains on record as one of "multiple wounds, including scalp." Trepanation in this case would have been unavailing, but it is quite probable that some of the other cases in this group should not only have been trephined, but should have had the dura opened as well, for eleven out of the number showed distinct evidence of moderate intracranial damage—a paraphasia, a partial or complete hemianopsia, or a slight motor or sensory monoplegia; and one or two severe scalp wounds of the vertex showed a certain degree of spasticity, indicating a bilateral contusion of the mesial portions of the hemispheres.

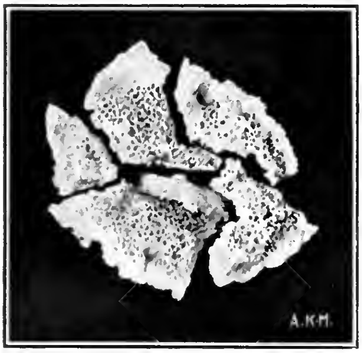


FIG. 463.—*Case* 3. The indriven fragments of inner table (natural size).

Among the cranial injuries of *Group II*, there are many examples of a slightly scored external table, and it is interesting to find that a larger proportion of these cases had intracranial symptoms than had those with a simple scalp wound. It is well known, however, that an intact external table may conceal an injury of the internal table, with serious cerebral contusions due to penetration of bone fragments. It is in cases of this kind that one's surgical judgement is put to the greatest test, for the temptation is great to follow a 'let alone' policy. Doubtless a temporizing policy is the wisest one if the scalp wound is seriously infected.

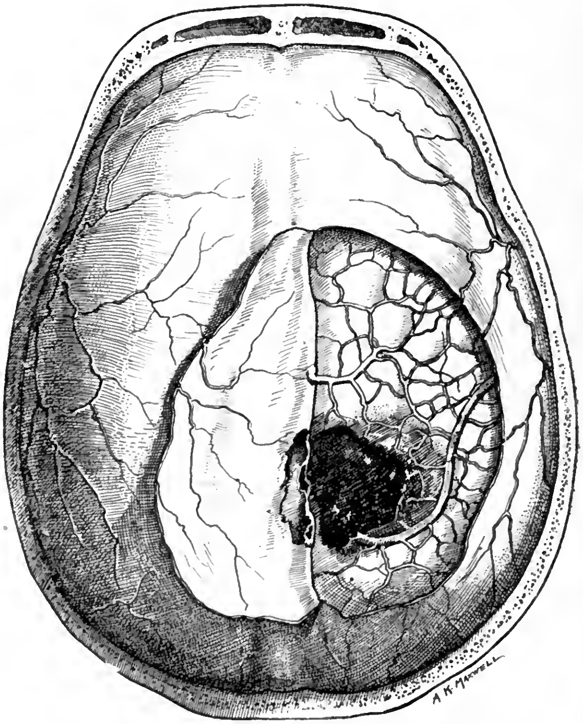


FIG. 464.—*Case* 3. From sketch at autopsy after removing calvarium.

The following case furnishes an example of a badly infected scalp wound with an apparently intact skull which probably would not have been trephined. The patient was on the pre-operation table after being shaved, and succumbed while awaiting his turn. The case, therefore, does not occur in the operation series.

Case 3.—Pte. J. G. **Spastic paraplegia. Very large gutter wound in mid-vertex. External table intact. Fragments of inner table driven through parasinoidal margin into hemisphere, with large area of disorganization. No operation. Death.**

Admission, Aug. 4, 1917, 2 p.m.—Wounded during the attack of July 31. Has been lying out since that time. Brought in by bearers to field ambulance this morning.

General Condition. — Profoundly unconscious; restless; cold. Pulse 140, irregular. Respiration 48, gurgling.

Wound. — A longitudinal gutter wound of vertex slightly to right of mid-line, 8 cm. in length. Margins very septic; stinking; containing maggots. In base of wound a dry, intact, denuded, external table was exposed. No *x*-ray examination.

Neurological Symptoms.—Apparent complete flaccid paralysis of left arm and leg. Patient moves right arm and leg, tearing at bandage with right hand. Deep reflexes exaggerated, with bilateral dorsal plantar response.

4 p.m.—Prepared for operation as a last resort. Died shortly after head was shaved.

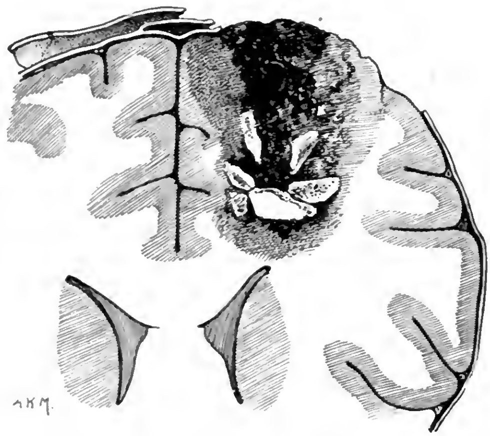


FIG. 465.—*Case* 3. Section through the contused area, showing position of bone fragments.

Autopsy.—The external surface of the calvarium is relatively intact (*Fig.* 461), with two or three fine linear radiating fissures extending across the parietal bone a short distance from the region of the scalp wound. On removing the calvarium, an area of inner table is found missing (*Fig.* 462), the fragments (*Fig.* 463), five in number, having been driven through an irregular tear in the dura adjoining the longitudinal sinus, the side of which has been torn into. One of the large veins entering the sinus (anastomotica magna) has been torn across, and the vessel is densely thrombosed (*Fig.* 464). The tear in the arachnoid measures 2 by 3 cm. The longitudinal sinus contains an ante-mortem clot, which extends forward from the site of the injury about 5 cm. Over the entire posterior hemisphere on the right is a thin superficial subdural clot. The left hemisphere appears normal. On section (*Fig.* 465), there is found a large area of cerebral disorganization, with a clot the size of a pigeon's egg in its centre. The bone fragments were found driven into the brain to a depth of 5 cm., just short of the ventricle.

An experience of this kind makes one hesitate to say that an intact skull should not be trephined, particularly when it overlies the longitudinal sinus. In view of his holding out so long, had this unfortunate man been brought in sufficiently early, an operation in all probability would have saved him.

We will return, when discussing the next group of cases, to the question of trepanation even when there is apparently an intact skull, for it cannot be too often or too emphatically emphasized that the essential feature of these cases is not the condition of scalp or skull, but the concomitant injury of the brain. One may find, indeed, that a scalp wound has left even the pericranium intact, and yet that the pericranium conceals a cranial fracture (cf. *Case* 10).

The configuration of the wound, unreliable as appearances are, is a more valuable index of associated cranio-cerebral lesions than its size, which varies from the smallest point, easily overlooked, to multiple wounds or to single

defects of huge dimensions. Some of the most seriously lacerated scalp wounds in the series were apparently produced by the helmet; for, when guttered by a large missile, the incurved edges of metal may plough through the scalp like a harrow, and lacerate it extensively. Indeed a man was admitted to an adjoining hospital with two incurved flaps of the helmet, reamed out like tin before a can-opener, actually penetrating the skull, so that the helmet was caught in the skull as though by a pair of tongs, and had to be cut away.

Fig. 466.—Perforation of helmet associated merely with scalp wound.

The largest scalp wound in the series was ploughed out in this way by the helmet (*Fig.* 466). It extended from the parietal eminence forward to the hair margin, a distance of 17 cm., and at its centre the lacerated area was 7 cm. in width. The skull was not even scratched, and the patient practically without symptoms, but the wound was too large to close.

Much more might be said concerning scalp wounds produced by projectiles, and the difficulties of being sure of their nature without operative investigation. On one occasion, after we had made a number of mistakes both ways, a wager was laid between the disputants regarding a certain wound which, though of the gutter type, appeared trifling and superficial, with no neurological symptoms. At operation, the fracture shown in *Fig.* 480 (p. 579) was disclosed.

Briefly, we may say that, unless disproved by investigation, a fracture may be supposed to underlie every scalp wound made by a projectile.

Group II.—LOCAL FRACTURES WITH INTACT DURA, WITH OR WITHOUT CEREBRAL CONTUSION.

In warfare it is naturally taken for granted that a cranial fracture is accompanied by a wound of the scalp; in other words, that it is a compound or open fracture occasioned by a projectile. This is usually, though not always, the case, for many extensive fractures of the skull occur from other causes—from falls, from being buried, or a heavy missile may impart to a helmet a sufficiently diffuse blow to cause a widespread fracture without external injury.

By far the larger number of wounds, however, are produced by an impact more or less local in its effect, with circumscribed injury to the scalp, bone, and brain, and one may make almost any number of subdivisions of these local cranial injuries.

In my former paper already referred to, they were divided into two groups: (1) Those in which the area of depressed bone showed the mosaic

of fragments more or less adherent; and (2) Those in which the fragments were detached and showered into the brain. The reason for making this distinction lay in the fact that the former type is usually, though not always, accompanied by an intact dura, and the latter with a lacerated membrane, the purpose of the paper having been to emphasize the particular risks to life associated with dural penetration.

In the present paper these various local injuries may be analyzed a little more closely, for the character of the bony injury must always remain a matter of interest, and have some influence upon any classification, even though the injury to the brain is admittedly the factor of chief importance.

The series contains 54 examples of local cranial injury which fall in this group: 28 of *Type A* (cf. diagram, p. 562), with the external table practically intact, with or without a verified depression of the inner table; 26 of *Type B*, with depression of both tables. In the latter type trepanation is indicated, even in the absence of neurological symptoms; in the former type trepanation must rest on one's judgement in the individual case.

An intact dura was certified by trepanation in 38 of the 54 cases, 29 of them having shown definite intracranial symptoms. The dura was presumably intact in the remaining 16 which were not trephined. These 16, in short, showed merely a simple graze or fissure of the bone, and, in the absence of neurological manifestations of a local contusion, they were treated as simple scalp wounds, with excision and closure without trepanation.

All of the 26 cases of *Type B*, with depressed external table, were trephined; neurological evidences of a focal lesion were pre-existent in 15, and in 6 the intact dura was incised owing to the disclosure of a local contusion, with 1 fatality. In contrast to this, 13 of the 28 cases of *Type A*, showing merely a graze or fissure of the outer table, were trephined owing to focal symptoms. A depression of the internal table was found only in 2 cases, but in 3 a large extradural clot was exposed, and in 5 others a tense plum-coloured dura overlying a contusion was found and incised.

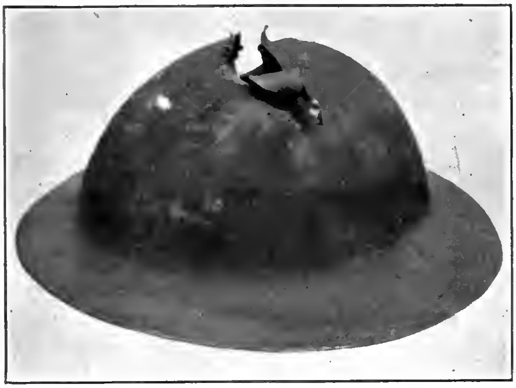
All told, there were 5 deaths in the 54 cases (mortality 9·2 per cent): one from septic bronchitis of gas poisoning, one from a gas-gangrene infection arising from a wound of the upper thigh, one from acute cerebral compression, one from a cerebral infection consequent on opening the dura, one from a secondary cranial operation in a home hospital on a patient with dura unopened at the casualty clearing station. There were, in short, 37 trepanations, with the dura incised in 11 cases, and 2 deaths; there were 16 cases not trephined, with 3 deaths. It will be seen from the case reports that some of the patients whose dura was not incised would probably have done better had the membrane been opened.

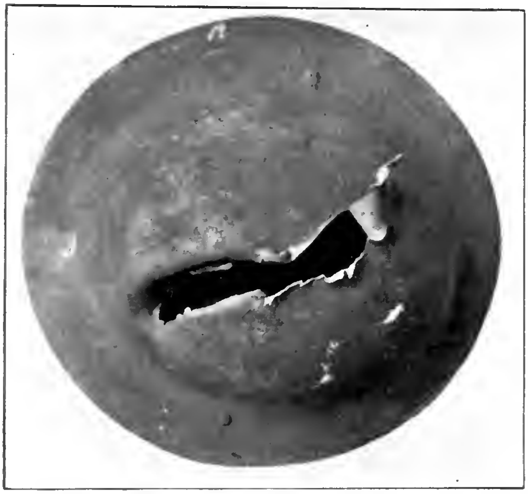
Type A. Local Fractures without Depression of External Table.—For the purposes of our present discussion, these lesser cranial injuries may be subdivided into: (1) Those with or without focal symptoms, but not trephined; (2) Those trephined owing to focal symptoms, but the dura left unopened; (3) Those trephined owing to symptoms, and the dura incised.

1. *Cases not Trephined.*—Three histories may serve to illustrate the first subdivision.

Case 4.—Rfm. S. F. (Serial No. 219).—**Large scalp wound. Mild sinus syndrome. Cranium slightly scored. Not trephined.**

Admission to C.C.S., Oct. 30, 1917, 6.45 p.m.—Wounded in the early morning: a piece of shell caught his helmet and made a deep gutter in it (*Figs.* 467, 468); no loss of consciousness; walked about three miles to field ambulance. Present condition good.





Figs. 467, 468.—Characteristic guttered helmet of *Case* 4, with scalp wound and slightly scored bone.

Wound. — A large lacerated gutter wound 9 cm. long, obliquely crossing the mid-vertex. No x-ray examination.

Neurological Findings.—Some stiffness of the lower extremities, with exaggerated deep reflexes, though without clonus or dorsal plantar response.

Operation, 9.30 p.m. (*circa* 15 hours).—Novocain. Dirty wound edges repaired, disclosing slightly scored bone containing two or three tiny cracks, in one of which a minute metallic foreign body was imbedded. Wound Carrelized and left wide open. Evacuated.

In the next example, owing to the dirty scalp wound and the improbability of its being closable, the skull was not trephined, in spite of the neurological evidence of a local contusion. As will be seen, the restoration of function has been very slow.

Case 5.—Sgt. J. G. (Serial No. 55).—**Mild sinus syndrome. Fissured fracture of vault. Not trephined. Imperfect recovery.**

Admitted to C.C.S., Aug. 16, 1917, 11.15 a.m.—Wounded by a shell at 9 p.m. of preceding day. Wearing helmet. Was knocked down, but not rendered unconscious. Immediate numbness of right foot. On attempt to get up and walk, "leg doubled under him."

General Condition.—Conscious; rational; cold; some headache. Pulse 92.

Neurological Findings.—Fundi slightly œdematous. Paralysis of right leg, with slight impairment of sensation. Right arm slightly weak, though patient attributes this to a former wound. Deep reflexes hyperactive, with slight clonus at right ankle. Plantar responses normal.

Wound.—Large, dirty, lacerated, transverse scalp wound on vertex, measuring 8 by 5 cm., slightly more to left than to right of mid-line. X rays show no abnormality.

Operation, 12 noon (15 hours).—Novocain. Excision of extensive scalp wound, disclosing a small fissured fracture directly over mid-line. Wound partially closed.

Aug. 18.—Slight power of flexion regained in right leg, but condition otherwise unaltered. Exaggerated reflexes persist on right. Evacuated.

Subsequent Reports.—Nov. 29 (by letter).—Complaint of dull headache with dizziness on exertion. Paralysis of right leg persisted for about three weeks, and though now able to walk with some stiffness, function has been very imperfectly regained. Dec. 28, report from officer at M.C.H., Hollywood.—Still some muscular weakness in right arm and leg; condition slowly improving. Some headache and dizziness on exertion, otherwise in best of health. Feb. 5, 1918 (by letter).—Complains of numb feeling in leg when he walks far; also of headaches; still in hospital.

The following is another example of the long delay in clearing up of the focal symptoms due to a contused area when the dura has not been opened and the disorganized brain removed. The conditions were favourable for dural incision, but the case occurred fairly early in the series, before this radical measure was often ventured upon.

Case 6.—Pte. S. W. M. (Serial No. 72). **Scalp wound with scored cranium. Not trephined. Persistence of focal symptoms.**

Admission to C.C.S., Aug. 22, 1917, 11.30 a.m.—At 6.30 a.m. was sitting in a concrete dugout which received a direct hit by a high-explosive shell. No loss of consciousness. Walked back one kilometre to an A.D.S., where he was made a stretcher case. Was wearing helmet, which was traversed by shell fragments (*Fig.* 469). Patient volunteers that during the course of the morning his left arm has "kept going dead," though there have been no definite focal seizures.

Fig. 469.—*Case* 6. Showing seriously damaged helmet of patient with but slightly scored cranium.

Condition.—Patient rational; body warm; pulse 64.

Wound.—A triangular-shaped wound to the right of the mid-vertex, supposedly penetrating. *X*-ray report: "No abnormality."

Neurological Findings.—Left arm and leg weaker than right; considerable hypæsthesia to all sensory stimuli; loss of muscle sense; complete astereognosis. Slight nystagmus to right. Deep reflexes within normal limits.

Operation, 2 p.m. ($7\frac{1}{2}$ hours).—Novocain. Tripod incision, disclosing a slight excoriation in the parietal bone without linear fracture. Patient not trephined, owing to pressure of more serious cases. Closure without drain. Evacuated.

Subsequent Reports.—Aug. 28, No. 2 Can. Gen. Hosp.—Slight headache; no neurological note. Evacuated to U.K. Sept. 19, Univ. Coll. Hosp.—Persisting weakness of left arm and leg, with loss of muscle sense in left arm. Jan. 1, 1918, Mitchie Hosp., Queen's Gate (by letter).—Weakness of left side subsiding. An *x*-ray plate reported to show an abscess (probably misread). Feb. 11 (by letter).—Discharged from hospital, Jan. 18; put in Grade B3; on fatigue duty at M.G. depôt; some headaches.

2. *Cases Trephined but Dura Unopened.*—The two following cases fall in the second subdivision. In the first case the external table was intact but the inner was fractured.

Case 7.—Pte. H. F. (Serial No. 73). **Scalp wound of vertex. Mild sinus syndrome. External table intact. Trepanation. Depressed inner table. Dura unopened. Slow recovery.**

Admitted Aug. 22, 1917, 1.30 p.m.—Field ambulance diagnosis: "S.W. vertex. Foreign body removed from scalp. Bone punctured but not penetrated." Remembers receiving a blow on his helmet; found himself buried and unable to move; dazed but not unconscious; was dug out and carried to aid station. In good condition: pulse 90.

Wound.—A contused circular scalp wound in the mid-vertex, exposing bone. No *x*-ray examination.

Neurological Findings.—Considerable weakness of lower extremities, particularly of right, where slight flexion of knee is possible, but no movement of foot. Deep reflexes exaggerated on right, with clonus and positive Babinski.

Operation, 4.30 p.m. (*circa* 10 hours).—Novocain. Scalp wound excised; two minute fragments of helmet lay adjacent to bone. External table intact; trepanation; fragments of inner table wedged down against the sinus; fragments dislodged without bleeding. Dura intact; not opened. Closure with extensive plastic flap.

Post-operative Course.—Aug. 25.—Wound without reaction. Temperature normal. Sutures removed. Aug. 28.—Neurological symptoms continue unaltered; weakness of left foot. Evacuated.

Subsequent Reports.—Sept. 4, No. 10 Gen. Hosp.—No note. Evacuated to England. Jan. 4, 1918 (by letter).—Discharged from service Dec. 20. No neurological symptoms; no headaches; can walk up to six miles comfortably.

One may not only have doubt in regard to the necessity of opening the bone which may appear normal, but at times even the pericranium may be intact and conceal a bony lesion. Occasionally, too, it is very difficult to tell from the external appearances alone whether or not there is actually a fungus cerebri; for a large pulsating blood-clot sometimes may simulate a cerebral protrusion, and the lesion, appearing to be a serious one, may prove to be nothing more than a lacerated scalp wound.

The following case not only illustrates these points, but also the slow restoration of function of a contused area when the dura has not been incised and the pulped tissue removed.

Case 8.—Pte. J. H. (Serial No. 178). **Superficial clot, simulating fungus. Fissured fracture of vault. Trepanation. Extradural clot.**

Admission Oct. 9, 1917, 3 p.m.—A diagnosis had been made of "S.W. head and fungus cerebri." Wounded by shell at 8 a.m.; wearing helmet. Temporary unconsciousness. Walked two or three kilometres to dressing station, the right arm and leg feeling somewhat numb.

General Condition.—Pale; cold; pulse 120, poor quality. Restless; yawning; nauseated. Large dressing soaked with blood. Wound exposed; bleeding, from what was taken to be a large fungus, checked with hot irrigation and pressure. Resuscitation ward: given morphia and saline. Condition improved during night. Pulse dropped to 100.

Neurological Findings, Oct. 10, 9 a.m.—Right arm and hand slightly weak, and "feel numb." Apparent loss of stereognostic and muscle sense, though no loss of common sensation. Deep reflexes hyperactive, without clonus. Normal plantar responses.

Wound.—A large lacerated wound in upper temporo-parietal region, filled with an oozing and pulsating mass. No *x*-ray examination.

Operation (after 25 hours).—Novocain. Wound excised, and found to be filled with a large protruding blood-clot instead of a supposed fungus. Pericranium intact; this was opened and reflected, disclosing a fissure in the bone. Trepanation:

large extradural clot disclosed and evacuated ; dura not tense. Closure of large defect by Isle of Man incision (*Fig.* 470). No drainage.

Post-operative Course.—Oct. 12.—Wound clean ; sutures removed. Astereognosis persists ; condition otherwise excellent. Oct. 14.—Strength in arm largely regained, and disturbance in muscle sense improving. Evacuated.

Subsequent Reports.—Oct. 16, No. 22 Gen. Hosp.—" Loss of position of right hand, with consequent astereognosis. Possibly slight hesitation in speech. Abdominal reflexes depressed on right."

Dec. 29 (by letter).—Discharged from Lord Derby War Hospital, Warrington, Dec. 27 ; slight feebleness of grip in right hand. General condition " fairly good." Jan. 12, 1918.— Weakness of hand and probably some loss of muscle sense persists ; also some hesitation in speech.

Fig. 470.—*Case* 8. Showing three-legged incisions to close large defect. Photograph on second day before removal of sutures.

3. *Cases Trephined and the Intact Dura Incised.*—In this, the most important subdivision, the procedure is unquestionably attended with certain risks of infection, and these one must weigh against the risks of permanent functional impairment if a considerable area of local disorganization is allowed to take care of itself.

There is a widespread impression that under no circumstances should the intact membrane be opened. This impression is born, I am sure, of early experiences in the war when technique was less perfect. Unless the external wound is very septic no great risk is run, provided the membrane is immediately closed with delicate silk sutures. Four of the eleven cases will be given in illustration.

Case 9.—Pte. A. L. A. (Serial No. 216). **Multiple scalp wounds of vertex ; linear fracture. Trepanation ; dura incised. Recovery.**

Admitted to C.C.S., Oct. 27, 1917, 7.15 p.m.—No history obtainable, owing to patient's condition. In resuscitation ward during night. Transferred to writer's team 1 p.m. on the following day.

Condition.—Stuporous ; slight reaction to supra-orbital pressure. Body warm ; pulse 88, good quality.

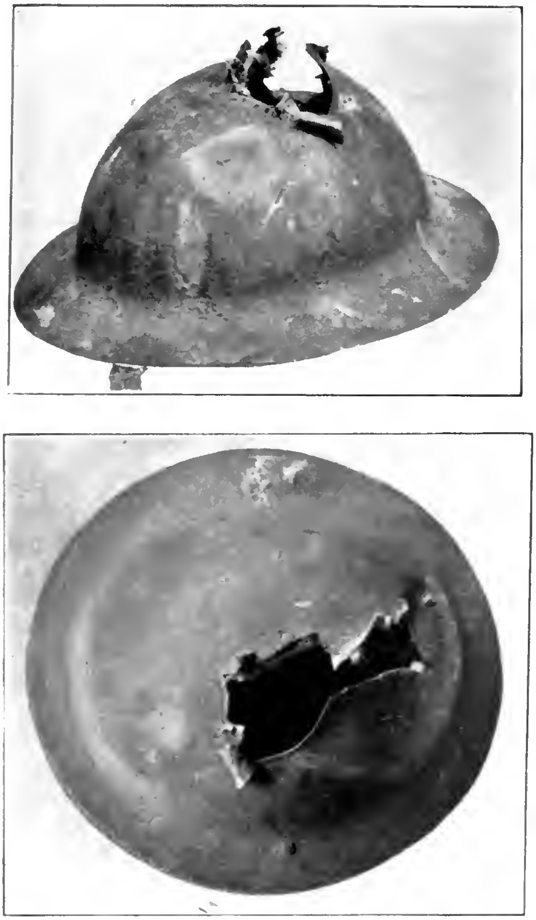
Wounds.—Multiple lacerated wounds of the vertex, chiefly to the right of midline and running in an oblique direction from behind forward, corresponding with the man's injured helmet (*Figs.* 471, 472). *X* rays show a fissured fracture of the right parietal, with no foreign bodies.

Neurological Findings.—Restless ; uses right side more than left. Right pupil slightly dilated. Deep reflexes exaggerated on left, with clonus and dorsal plantar response.

Operation, Oct. 28, 3 p.m. (*circa* 24 hours).—Novocain. The two larger lacerated gutter wounds were excised, one of them proving to be merely a scalp wound, but the anterior one overlay a short linear fracture through which blood was

oozing. Circular trepanation, disclosing a tense, discoloured, intact dura. Dura was incised, and about 2 oz. of dark semi-fluid blood-clot was evacuated, immediately lowering the tension. Arachnoid everywhere intact and of good colour. Dura re-sutured.

Oct. 29.—Consciousness regained; responds fully to questions; no recollection of the occurrence nor the events subsequent to his injury. Oct. 31.—Considerable headache. Lumbar puncture: clear fluid in some excess. Nov. 5.—Perfect wound healing. Temperature and pulse tend to subnormal (*Fig.* 473). General condition good. Rapid return of motor power in left side. Evacuated.



FIGS. 471, 472.—Helmet of *Case* 9, with linear fracture and cerebral contusion.

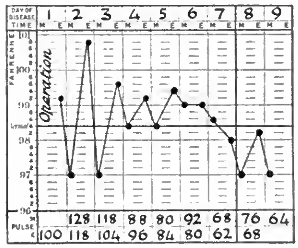


FIG. 473.—Chart of *Case* 9; tendency to slow pulse and subnormal temperature.

Subsequent Report.—Jan. 10, 1918 (by letter).—Still at King George Hospital. Up all day; no trouble with left side. Occasional headache.

In the next example, as in *Case* 8, the pericranium was uninjured and concealed a fracture. The case possibly belongs in reality with the group of bursting fractures, though the bone comminution was centralized under the scalp wound. The patient was in a critical condition, but improved after the evacuation of the disorganized area and subsequent lumbar punctures.

Case 10.—Pte. C. S. (Serial No. 111). **Scalp wound. Intact pericranium. Depressed fracture. Dura incised. Recovery.**

Admission, Sept. 17, 1917, 6.45 p.m.—No story obtainable owing to patient's stupor. Field medical card of same date: "G.S.W. skull; compound fracture."

Condition.—Semiconscious; vomiting; pulse 56. Can be roused by supra-orbital pressure, but responses are vague and unintelligible.

Wound.—Ragged gutter type, 8 cm. in length, over right parietal region; supposedly penetrating; a pulsating mass taken to be a hernia cerebri. *X*-ray report: "Fracture of right parietal. No indriven fragments."

Neurological Findings.—Paralysis of left arm and leg, with apparent loss of sensation. Possible weakness of left face, shown on wincing. Tendency to conjugate deviation of eyes, with marked rotation of head to right. Deep reflexes hyperactive, with suggestion of clonus on the left and a positive Babinski.

Operation, 11 p.m.—Novocain. The ragged dirty scalp wound excised: found to be filled with a clot without protruding brain: an intact pericranium disclosed. Pericranium incised, exposing a pond-shaped, slightly depressed fracture with many radiating fissures. Trepanation: removal of the area of depression. Dura intact, but tense and bluish. Membrane incised: large amount of blood-clot, cerebrospinal fluid, and disorganized brain tissue removed. Bleeding vein on the surface of the arachnoid secured with a clip. Dura closed: dichloramine-T: scalp wound closed by plastic flap.

Sept. 18.—Still semiconscious. Lumbar puncture: 20 c.c. of bloody, slightly turbid fluid; culture—coliform bacilli (Captain Leitch). Sept. 19.—Still unconscious. Swallowing badly. Very restless, requiring morphia. Second lumbar puncture: 25 c.c. of fairly clear fluid: culture sterile. Sept. 21.—A series of left-sided Jacksonian fits. Sept. 25.—Responding for first time to-day. Temperature normal. Wound clean. Left hemiplegia still present. Sept. 26.—Moving left leg for the first time. Sept. 27.—Condition excellent, though temperature and pulse tend to be subnormal (*Fig.* 474). Conscious. Responds to questions with intelligence, though no memory of preceding events. Evacuated.

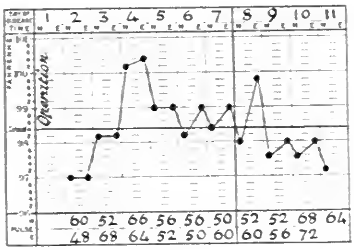


FIG. 474.—Chart of *Case* 10.

The following story records a practically intact skull accompanied by symptoms indicating a local contusion. It is quite likely that this combination may occur more frequently in the temporal region than elsewhere, though, on the other hand, owing to the fragility of the squamous bone, one might anticipate finding a fracture more often here than elsewhere. All this depends doubtless on the structure of the bone in the individual case.

Case 11.—Pte. T. C. (Serial No. 69). **Seton wound through temporal region. Focal symptoms. Cranium practically intact. Trepanation. Dura incised.**

Admission, Aug. 20, 1917, 7 a.m.—Wounded 4 a.m. by shell fragment penetrating helmet. Temporary unconsciousness. Severe headache; dizziness and vomiting. Primary numbness of right arm and leg, followed by weakness.

Condition.—Intellect unimpaired. Body warm. Pulse 68.

Wound.—Glancing wound of left temporal region, with entrance and exit (*plaie en séton*). *X*-ray examination negative.

Neurological Findings.—Weakness of entire right side, with slight hypæsthesia of right face. Some slowness of speech, but no definite aphasia (patient right-handed). Deep reflexes exaggerated and equal; no clonus.

Operation, 11 p.m. (19 hours).—Novocain. Flap procedure: reflection of most of left temporal muscle. Bone slightly scored. Trepanation of an area 3 by 3 cm. Intact dura, tense and bluish. Membrane opened: disorganized brain with many clots evacuated, completely relieving tension. Dura sutured. Flap replaced: sutured in layers. A single gutta-percha drain inserted through unexcised track of missile.

Post-operative Course.—Excellent recovery. No headache; sutures removed and drain withdrawn on second day. Rapid subsidence of right-sided palsy. Temperature and pulse tend to subnormal. Evacuated.

Subsequent Reports.—Sept. 5, No. 8 Gen. Hosp.—Slight weakness of right arm

persists, otherwise normal. Evacuated to U.K. Jan. 10, 1918 (by letter).—In convalescent depôt. Good condition, aside from some headache and dizziness on stooping.

There follows the story of another wound which might easily have passed for a simple scalp wound, but in view of the neurological symptoms indicating a local contusion, not only was the apparently intact skull trephined, disclosing a fracture of the inner table, but an intact dura was opened, with removal of devitalized cerebral tissue.

Case 12.—Pte. H. T. (Serial No. 91). **Trepanation, disclosing depressed fracture confined to inner table. Incision of intact dura. Cleansing cf pulped area. Closure. Rapid restoration of function.**

Admission, Sept. 3, 1917, 5 p.m.—Wounded at mid-day by shell fragment penetrating helmet. Knocked down, but not unconscious. Walked fifty yards without assistance, though left side felt numb and dead. In good general condition ; pulse 70.

Wound.—Small, apparently superficial, right parietal region. *X*-ray findings negative.

Neurological Findings.—Patient left-handed ; no apparent speech defect. Tongue protrudes to left. Complete left hemiparesis involving the arm, leg, and lower face. Arm chiefly affected. Complete loss of sense position of left hand, with astereognosis. Deep reflexes active to exaggeration on left, but without clonus. Normal plantar responses.

FIG. 475.—*Case* 12 on discharge, sixteenth day.

Operation, 9 p.m. (9 hours).—Novocain. A vertical incision as for a subtemporal decompression, circumscribing the small scalp wound. Skull apparently intact. Trepanation *en bloc*, 3 cm. in diameter, disclosing fracture with depression of internal table, but an intact dura.

The membrane showed no discoloration or undue tension. It was incised, and a large contusion of the central Rolandic area was exposed, with an abundance of clots, cerebrospinal fluid in excess, and a severely contused area. Careful toilette of this area, with removal by irrigation and suction of clots and pulped brain. Closure of dura ; scalp closed with buried galea sutures ; no drainage.

Post-operative Course.—Convalescence uninterrupted. Highest temperature 99°. Primary healing (*Fig.* 475). Normal sense of position of fingers and hand regained, with ability to recognize objects. Muscle power in arm and leg practically restored. Slight weakness of face persists on expressional movement. By Sept. 19 condition practically normal. Evacuated.

Subsequent Reports.—Sept. 22, No. 13 Gen. Hosp.—No residual paralyses. Condition excellent. Transhipped. Oct. 15, York Military Hosp.—Occasional headaches, otherwise condition normal. Discharged to Sunderland War Hospital. Jan. 1, 1918.—Letter from patient's mother, who wishes to know why a piece of bone from his shin has been put in his head—an unanswerable query. Jan. 20 (by letter).—

Says his hemiplegia has completely recovered except for a slight weakness of left thumb. Bone-graft operation regarded as a great success, but headaches and dizziness on stooping remain unaffected.

This patient doubtless would have recovered from the immediate effects of his injury without trepanation or opening the dura, but the rapid return of function, particularly when compared with other unoperated cases exhibiting similar symptoms, shows the desirability of removing the devitalized cerebral tissue if it can be done with reasonable safety, for there doubtless is very much less reparative reaction afterwards. Cases in which the disorganized brain has been left to care for itself appear to have had a more tardy convalescence and slower restoration of function.

Type B: LOCAL FRACTURES WITH DEPRESSION OF EXTERNAL TABLE.—These fractures, a few examples of which may be given, offer problems which in many ways are easier, for there can be no question regarding the wisdom of trepanation, whether neurological symptoms are present or wanting.

The following case is of interest in view of the minute size of the foreign body—a fragment of helmet—which seemingly produced the depression and cerebral contusion. The dura was not opened, owing to the infected scalp, and there was a temporary increase in the symptoms after the operation, presumably due to the pressure from œdema about the contused area.

FIGS. 476, 477.—Showing outer and inner tables of *Case* 13: dura intact.

Case 13.—Rfm. W. H. (Serial No. 122). **Depressed fracture from minute fragment. Dura not incised. Post-operative increase in local symptoms.**

Admission, Sept. 21, 1917, 2 a.m.—Wound received at 6 a.m. on previous day, soon after going over parapet. Was rendered unconscious; crawled back to a shell hole; bandaged by a companion. Recovered by bearers at 8 p.m.

General Condition.—Conscious; rational; somewhat dull. Pulse 80, good quality.

Wound.—Gutter type, 5 cm. in length; left parietal eminence; edges indurated and infected. *X*-ray report: "Fracture of left parietal; indriven bone with minute intracranial metallic foreign bodies."

Neurological Findings.—Fundi œdematous. Weakness of right arm, without sensory disturbance. Deep reflexes exaggerated; equal.

Operation, Sept. 21, 3 p.m. (33 hours).—Novocain. Excision of septic scalp wound. Exposure of small depression of external table; minute fragment of helmet imbedded. Trepanation *en bloc*, disclosing unexpected degree of comminution of inner table (*Figs.* 476, 477). Dura intact; bluish, but no great tension. Not opened, owing to infected scalp. Closure without drainage.

Sept. 22.—Numbness and weakness of right arm very much more marked to-day. Considerable headache. Sept. 23.—Condition satisfactory. Evacuated.

Subsequent Reports.—Sept. 30, No. 2 Stationary Hosp.—Sutures removed; perfect healing. No neurological note. Evacuated to England.

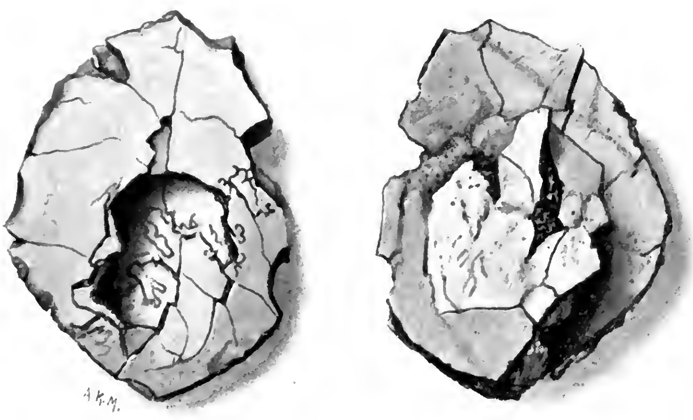
Another example may be given of the consequences of not opening the dura when local symptoms indicate the presence of a cerebral contusion. As is not uncommon under these circumstances, there was a post-operative increase of the paralysis, associated with Jacksonian fits.

Case 14.—L.-Cpl. H. W. (Serial No. 138). **Gutter wound. Compound depressed fracture. Local symptoms. Dura not incised. Increase of symptoms, with focal epilepsy.**

Admission, Sept. 26, 1917, 1.45 p.m.—Wounded 10 a.m. by rifle ball (?). Wearing helmet. Knocked down, but not unconscious. Subsequently severe headache; numbness and weakness of left side; was able to get back to A.D.S. with aid of a prisoner.

General Condition.—Good; body warm; pulse 98.

Wound.—Lacerated gutter type, 8 cm. in length, extending from right frontal eminence backward and toward mid-line. *X*-ray report: "Depressed fracture, with linear fissures radiating toward vertex and occiput. Small metallic fragments at site of depression."



Figs. 478, 479.—Showing outer and inner tables of *Case* 14: dura intact.

Neurological Findings.—Optic discs œdematous, with obliteration of cup, laminæ, and nasal margin. Right pupil larger than left; tendency to conjugate deviation of eyes to the right. Weakness of left arm, leg, and face, without sensory loss. Deep reflexes brisk and equal.

Operation, Sept. 26, 6 p.m. (8 hours).—Novocain. Excision of scalp wound, disclosing a depressed area (*Fig.* 478) from which many linear fractures radiate. Block trepanation. Inner table fragmented and much depressed (*Fig.* 479). Dura intact. Extradural clots removed. Partial closure.

Sept. 28.—Lumbar puncture: fluid clear. General condition good, although left arm more helpless than before. Sept. 30.—Repeated attacks of focal epilepsy,

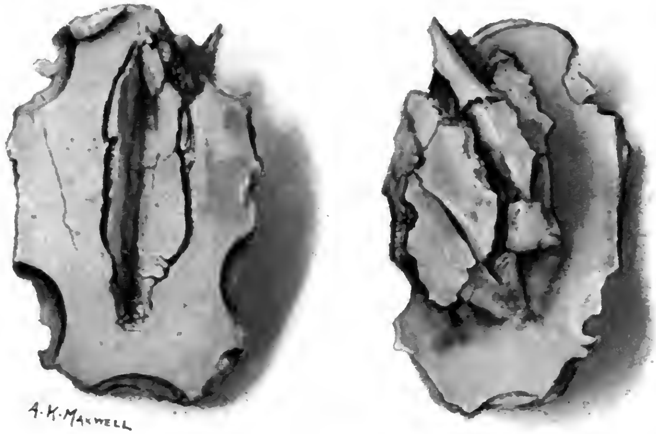
chiefly in shoulder-girdle muscles, associated with turning of the head and eyes to the left. Paralysis of left arm complete. Extensive subconjunctival ecchymosis. Sutures removed. Wound in good condition. Oct. 3.—Occasional recurrence of focal attacks ; general condition good ; paralyses unaltered. Evacuated.

Subsequent Reports.—Oct. 6, No. 16 Gen. Hosp.—Persisting weakness of face and arm. No seizures noted. Evacuated to U.K. Jan. 2, 1918, Fair Lawn Auxiliary Hospital (by letter).—Some slight persisting numbness in fingers, and occasional twitching in left face ; otherwise regards himself as well. Feb. 27, Lond. Gen. Hosp.—Focal epilepsy ; discharged permanently unfit.

There follows the story of what was supposed to be a simple scalp wound ; indeed, as heretofore stated, a wager to this effect had been placed. A depressed fracture without dural injury was disclosed. As there were no focal symptoms, the membrane was not opened.

Case 15.—Pte. S. H. W. (Serial No. 62). **Extensive depressed fracture of occipital region over torcular. No focal symptoms. Dura intact; not incised.**

Admission to C.C.S., Aug. 16, 1917, 7.30 p.m.—Wounded at 11.30 a.m. by shell fragment ; stunned but not unconscious. Made his way back on foot, reaching the field ambulance at 3 p.m.



FIGS. 480, 481.—Showing outer and inner tables of *Case* 15 : dura intact.

Condition.—Conscious ; rational ; warm ; pulse 80.

Wound.—An inverted V-shaped scalp wound in mid-line over occiput. *X*-ray report : "No foreign body ; questionable fracture."

Neurological Findings.—Practically nil. No hemianopsia or visual disturbance. Deep reflexes equal : exaggerated ; without clonus.

Operation, Aug. 17, 11 a.m. (24 hours).—Novocain. On excising the supposed scalp wound, a depressed gutter fracture (*Fig.* 480), directly overlying the torcular, was exposed. Trepanation *en bloc* disclosed a widely depressed area of inner table, with fragments indriven to a depth of 1 cm. (*Fig.* 481). Dura intact. Closure without drainage. Immediate evacuation.

Subsequent Reports.—Sept. 12, No. 3 Gen. Hosp.—No complications. Primary healing. Evacuated to U.K. Nov. 12, Military Hospital, Richmond.—Boarded out as P.U. Occasional slight headache. No other symptoms. Jan. 9, 1918 (by letter).—Discharged from service Nov. 15, 1917. Feels perfectly well. "Advised to wear a celluloid plate to protect head."

Another example may be given of the rapid disappearance of symptoms following incision of the dura and evacuation of the underlying softened and contused area. The cranial wound was relatively insignificant.

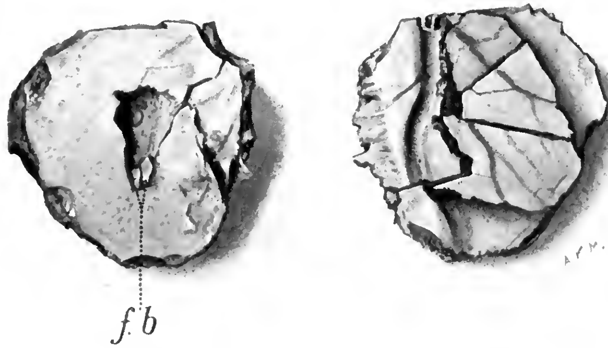
Case 16.—Pte. J. F. (Serial No. 173). **Small compound depressed parietal fracture. Focal symptoms. Intact dura incised. Recovery.**

Admitted Oct. 4, 1917, 11.50 p.m.—Accompanying diagnosis: "Bullet wounds of head and neck. Fractured skull." Oct. 5, 9 a.m.—In resuscitation ward during night. Imperfect history. Wounded some time in the afternoon. Wearing helmet (?). Temporary unconsciousness (?). Present condition good, though somewhat confused and drowsy. Headache.

Neurological Findings.—Left pupil dilated. Weakness and lowered sensitivity of entire right side, involving face and leg, but most marked in arm, with loss of muscle sense and astereognosis. Memory and orientation defective. Slight difficulty in finding his words. Deep reflexes sluggish; equal.

Wounds.—(1) Of penetrating type, 3 cm. to left of mid-line over fronto-parietal region; (2) Multiple small penetrating wounds, right face and neck. *X*-ray report: "Depressed fracture, with indriven bone fragments and multiple small foreign bodies both in cranial wound, face, and neck.

Operation, 3 p.m. (*circa* 23 hours).—Novocain. Usual three-legged incision; small depression found in outer table, with fragment of helmet wedged in the bone



Figs. 482, 483.—Showing outer and inner tables of *Case* 16: dura intact.

(*Fig.* 482). Radiating lines of fracture pass to the side. Trepanation *en bloc*: widely depressed area of inner table adjoining deep groove of meningeal artery (*Fig.* 483). Dura intact, though somewhat tense and bluish. Linear incision of membrane, with evacuation of about 30 c.c. of semi-fluid clot and pulped brain; expulsion aided by the patient's coughing. Dura re-sutured after usual toilette of cavity by suction and irrigation. Multiple wounds elsewhere individually treated.

Oct. 11.—First dressing: wound perfect (*Fig.* 484); sutures removed. Normal power regained in face and leg: arm less awkward. Oct. 14.—Arm greatly improved; lost sense of position largely restored with present capacity to recognize objects. Deep reflexes remain very sluggish. Evacuated.

Subsequent Reports.—Oct. 16, No. 18 Gen. Hosp.—"Excellent condition. Slight weakness of right hand. Evacuated." Jan. 9, 1918, 4th London Gen. Hosp.—Normal condition, except for trace of weakness in hand.

The Fatal Cases.—There were 5 in the series of 54: a mortality of 9·2 per cent. Two fatalities occurring early in the series—one due to failure to open the dura, the other to the fact that it was opened but not immediately

closed—were avoidable, had better judgement been exercised. A third case was practically moribund when operated upon. The fourth and fifth died of concomitant lesions.

The first fatality in this group occurred six weeks after the injury, subsequent to an operation in England for a cerebral abscess that had formed below the intact dura which had not been incised.

Case 17.—Sgt. R. D. K. (Serial No. 11).

July 31, 1917.—Multiple wounds of head and face, including depressed fracture of right parietal region. Left hemiparesis, chiefly of arm. Removal piecemeal of depressed bone-fragments; dura intact; not incised. Evacuated Aug. 6.

Subsequent Reports.—Aug. 14, No. 83 Gen. Hosp.—Condition good; wound healed; some headache: evacuated U.K. Oct. 11, King George Hosp.—Death from meningitis following operation for abscess in right hemisphere.

Fig. 484.—*Case* 16. Example of tripod incision.

The second fatality was clearly attributable to the surgical opening of the dura—or more properly to the failure to close the incision. A staphylococcal infection of the external wound spread to the meninges.

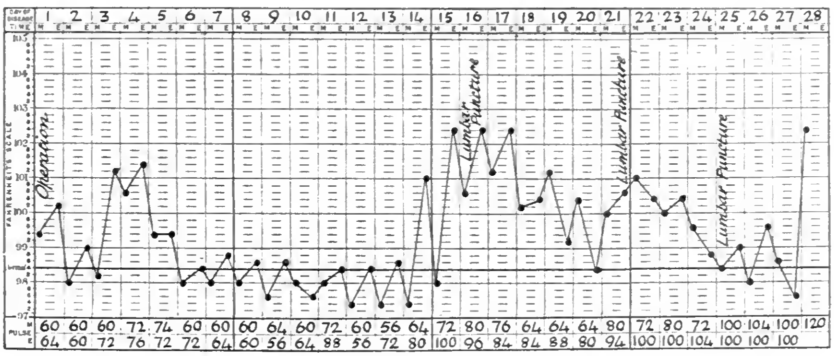


Fig. 485.—Chart of *Case* 18, showing onset of complication on thirteenth day.

Case 18.—Pte. J. L. (Serial No. 59).

Aug. 17, 1917.—Admitted unconscious; pulse 52. A transverse gutter wound of occiput. Novocain operation: linear fracture without depression; tense plum-coloured dura; membrane incised; toilette of greatly pulped left occipital lobe. Dura not sutured. Closure of scalp wound by plastic flap.

Aug. 20.—Consciousness regained. Right homonymous hemianopsia disclosed. Slight necrosis of edges of flap from imperfect circulation. Aug. 27.—Flap protruding. Aug. 31.—Cerebrospinal leak, with rise in temperature (cf. chart, *Fig.* 485). Urotropin. Sept 2.—Lumbar puncture: *Staphylococcus aureus*. Sept. 7.—Lumbar puncture: a coccus in diplococcal form. Sept. 11th.—Cerebrospinal leak continues, but symptoms of meningitis are less marked. Lumbar puncture: clear yellowish fluid, sterile. Temperature normal. Sept 13.—Sudden rise in temperature. Death.

Autopsy.—Cerebrospinal spaces filled with plaques of purulent exudate.

The third fatality occurred a few hours after a futile attempt to save a desperate case by decompression.

Case 19.—Pte. McD. (Serial No. 185).

Sept. 25, 1917.—Unconscious; stertorous breathing and rapid pulse. Gutter wound of vertex, with rigidities. Choked disc 2 D. Right subtemporal decompression: no anæsthetic. Death in two hours; temperature 105°.

Autopsy.—Gutter wound of scalp; external table intact; inner depressed; dura intact; brain widely contused and œdematous.

The fourth fatality was attributable to multiple wounds and severe gas poisoning, as follows:—

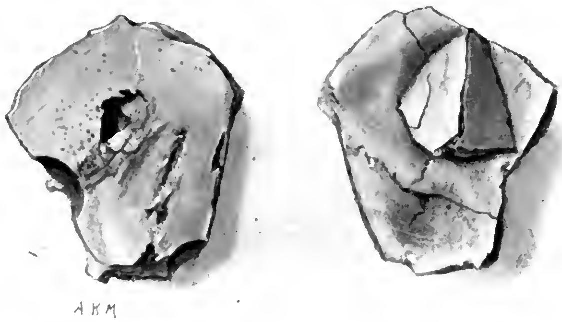
Case 20.—Pte. A. B. (Serial No. 157).

Sept. 19, 1917.—Lying-out case; severely wounded and gassed two days ago. Condition critical; pulse 120; temperature 102°; vomiting. Severe wounds of arm and shoulder; three gutter wounds of scalp. Resuscitation ward for six hours; bicarbonate.

Operation.—Amputation of arm; temporary repair of scalp wounds, without closure. Death in 24 hours, pulmonary complication.

Autopsy.—Purulent bronchitis: bronchopneumonia; depressed fracture of skull in occipital region; dura intact; contusion of occipital lobe.

The fifth fatality was due to a gas-bacillus infection of buttocks and thigh.



FIGS. 486, 487.—Showing small depression (fatal) of *Case* 21: dura intact.

Case 21.—Gnr. A. J. (Serial No. 195).

Oct. 19. 1917.—Perforating wound of upper thigh; large gutter wound of left occiput, appearance simulating fungus cerebri; right homonymous hemianopsia.

Operation (*circa* 36 hours).—Novocain. Trepanation *en bloc*; minute depressed fracture (*Figs.* 486, 487); dura tense, plum-coloured; incised; extrusion of much clot and pulped brain; closure of dura; dichloramine-T; closure of scalp by flap. Repair of infected gassy wound of upper thigh: recovery of large 50-grm. shell-fragment: free excision of damaged muscles: drainage. Rapidly spreading gas infection of thigh and buttock, with death on following day.

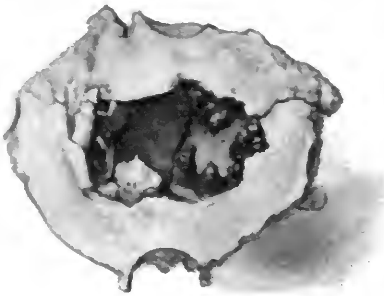
Autopsy.—Extensive gas infection of upper thigh and buttock; brain without evidence of infection.

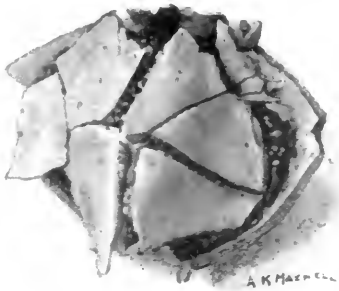
Group III.—WOUNDS WITH LOCAL DEPRESSED FRACTURES, LACERATION OF THE DURA, AND CEREBRAL CONTUSION.

These are favourable cases, in spite of the fact that the meninges have been torn or punctured by a projecting spicule of bone. Hence they may be considered in a group by themselves, for even though the scalp wound may be grossly contaminated, there is no immediate risk of intracranial infection establishing itself, since the more or less intact mosaic of bone fragments remains interposed between the external wound and the brain, and extrusion of brain substance is uncommon.

Usually both tables are depressed, though this is not invariable, for, as in the preceding group, the bone may merely be fissured or scored, or indeed be intact. It is not improbable that many fractures of this type remain unverified, particularly when the lesion overlies the mid-vertex and is accompanied by the so-called longitudinal-sinus syndrome, in the presence of which Sargent and Holmes have advised against trepanation.

The series contains 18 examples of certified fracture of this type, with 2 fatalities, one of them from intercurrent causes. One may conclude, therefore, that the prognosis is almost as good as in the cases of depressed fracture





FIGS. 488, 489.—*Case* 22. Mid-occipital fracture : mosaic of depressed fragments intact.

without punctured dura, provided there are no serious complicating injuries. For this reason these cases have been separated from those with dural penetration of other forms in which the prognosis is grave.

Anatomically, the wounds were distributed as follows : parietal (including vertex) 8, occipital 4, frontal 4, temporal 2. The associated scalp wounds were of the following types : gutter 10, seton 1, penetrating 7 ; five of the cases had seriously complicating wounds elsewhere. The missiles, so far as recorded, were : shell fragment 13 (9 certified, 4 presumable), rifle ball 2, shrapnel 1, bomb 1, secondary missile 1 ; in depressed fractures of this kind it is not uncommon to find the missile lodged in the seat of fracture. The helmet was recorded as worn in 12, not worn in 3, uncertain 3 ; it was known to have been penetrated in 5, presumably penetrated in 4, and in 2 the missile passed below it.

Occipital Wounds.—The following is a good example of the *Group III* type of injury. It is the only one of the occipital cases in which there was no gross disturbance of central vision.

Case 22.—Seaman E. L. (Serial No. 202). **Mid-occipital depressed fracture; double slight laceration of dura; cerebral contusion slight. Recovery.**

Admitted, Oct. 22, 1917, 3 p.m.—History of receiving an H.E. shell-wound at 11 a.m., while in the line. Was wearing helmet. Knocked down, but not unconscious. Made his way back unaided, though having headache and occasional vomiting.

Fig. 490.—*Case* 22. Showing wound with tripod incision on evacuation; sixth day.

General Condition.—No shock; fully conscious; pulse 84, regular.

Wound.—Lacerated, of penetrating type, over the mid-occiput. *X*-ray report: A depressed fracture; no metal.

Neurological Findings.—Nil: no apparent constriction of visual fields.

Operation, 5 p.m. (6 hours).—Novocain. Tripod incisions encircling wound; depressed fracture of the outer table (*Fig.* 488), lying directly over the mid-line. Preparations made for muscle graft, as hæmorrhage from sinus was anticipated. Trepanation *en bloc*: mosaic of depressed inner table intact (*Fig.* 489); marked depression of the underlying dura, with a small laceration on each side of the sinus, the main channel itself uninjured; graft unnecessary. Closure of wound in layers.

Oct. 28.—Convalescence uninterrupted. Wound without reaction (*Fig.* 490). Patient up; no symptoms. Evacuated.

Subsequent Reports.—Dec. 12 (by letter).—At No. 7 Canadian General Hospital two days; evacuated to Seaforth Military Hospital in Leith—eleven days. Transferred to an Auxiliary Red Cross Hospital for three weeks, and after ten days at home returned to his base: Class B2. Some tendency to headaches and dizziness. Feb. 17, 1918 (by letter).—In good health; on service in Italy.

In the three other occipital cases in the group the usual neurological evidences of an injury in this region were present. One of them had a complete central blindness, and the other two a sharply-cut hemianopsia.

The example of complete blindness occurred in an officer (Serial No. 104) with a shell wound which penetrated his helmet. There was immediate complete loss of vision. He was operated on after about ten hours, and under an intact pericranium a stellate depressed fracture over the lambda was found, with a tear in the dura. There was no very evident contusion of the occipital lobes. Light perception began to be regained after forty-eight hours, after which it continued to clear very rapidly to normal.

The other two cases showed hemianopsia; both had lesions over the lateral sinus. In one of them the cerebellum was damaged as well as the occipital lobe. The case follows:—

Case 23.—Pte. W. A. G. (Serial No. 93). **Gutter fracture of right occiput; laceration of occipital dura and lateral sinus. Cerebellum contused under intact dura; incised. Recovery.**

Admission, Sept. 3, 1917, 7.25 p.m.—Wounded at 10 a.m. Was wearing helmet, and states that the projectile (shell fragment) went below it.

General Condition.—Good, though somewhat dull and vague mentally.

Wound.—Vertical, of deep gutter type (*Fig*. 491), behind right mastoid. Some bleeding from external ear. *X*-ray report: Depressed fracture with indriven bone.

Neurological Findings.—Sharply-cut left homonymous hemianopsia. Deep reflexes brisk to exaggeration. No cerebellar symptoms detected beyond slight nystagmus.

Operation, Sept. 4, 10 a.m. (24 hours).—Novocain; cerebellar table. Excision of scalp wound; reflection of sub-occipital flap, showing an occipito-petrosal comminution, with indriven fragments. Piecemeal removal of the fragments disclosed a penetration of the dura over the occipital lobe, with a marginal tear of the lateral sinus, which was secured by a silver clip. The sigmoid sinus was also injured by a large loose fragment, which was not dislodged, as efforts to do so caused a sharp venous hæmorrhage. One large detached fragment apparently opened into the middle ear. Through the dural opening a large amount of disorganized brain with blood-clots was cleaned out by the usual method. Dura over cerebellum very tense and bluish; membrane incised, with evacuation of a large blood-clot and bloody cerebrospinal fluid; incision closed. Scalp wound closed with single gutta-percha drain.

Fig. 491.—*Case* 23. Gutter wound of occipito-mastoid region with occipital and cerebellar contusions.

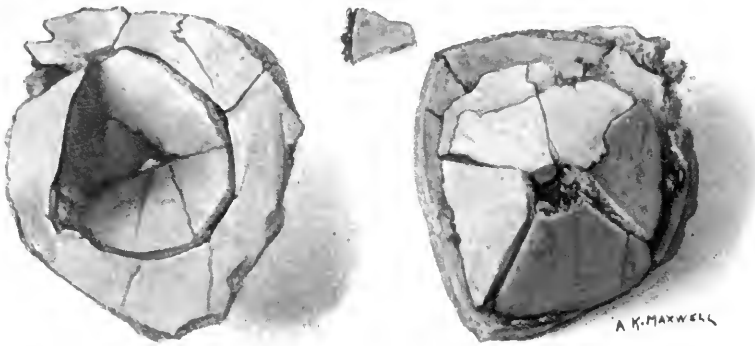
Sept. 19.—Perfect wound healing; normal temperature. Convalescence complicated by a small carbuncle on the neck: excised. Sept. 21.—Condition excellent. Some apparent return of vision in the left visual fields. Evacuated.

Subsequent Reports.—Dec. 22, King George Hospital (by letter).—Occasional headaches; deaf in right ear. Slight remaining contraction of field of vision. No other neurological symptoms. Jan. 20, 1918.—A series of boils have detained him in hospital. Discharged unfit, owing to contracted vision.

Feb. 16.—At work: well, except for some headaches and persisting deafness of right ear.

Frontal Wounds.—Taking the series as a whole, it is our impression that the occipital cases are apt to do less well after operation than frontal ones. The frontal wounds are more accessible, surgically speaking, and despite the mental disturbance which may accompany them, and the tendency of the patients to disarrange their dressings, they have usually done well.

The following case is an example of a depressed frontal fracture, with intact mosaic of fragments except for the dislodgement of a small central piece which had penetrated the dura.



FIGS. 492, 493.—Operative block of *Case* 24, showing depression with intact mosaic except for one central detached fragment which was driven through dura.

Case 24.—Sgt. W. T. (Serial No. 175). **Frontal gutter wound; depressed fracture; mosaic incomplete; dura penetrated. Recovery.**

Admission, Oct. 9, 1917, 11 a.m.—Wounded by a shell while in the reserve line, at 7 a.m. Missile passed below helmet. Knocked down; stunned; consciousness not lost. Walked back to dressing station; severe headache; vomited once.

FIG. 494. *Case* 24. Showing wound on tenth day: tripod incisions nearly invisible.

General Condition.—Good. Pulse 78. Fully conscious and oriented.

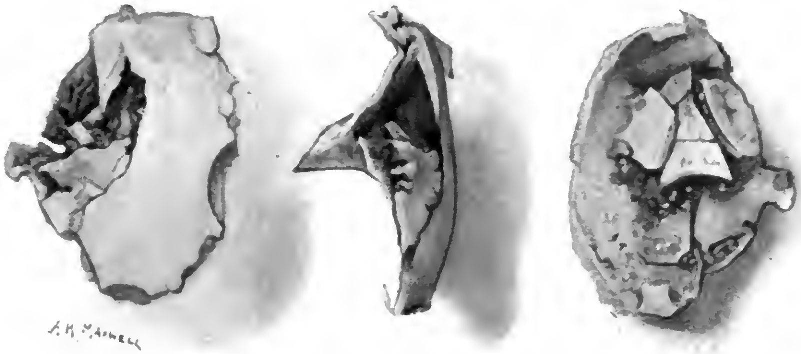
Wound.—Of gutter type; left frontal. *X*-ray report: "Depressed fracture with slightly indriven bone. No foreign body."

Neurological Findings.—Negative. Deep reflexes brisk to exaggeration.

Operation, 3 p.m. (8 hours).—Novocain. Tripod incisions encircling gutter scalp wound. Trepanation *en bloc* (*Figs.* 492, 493); mosaic of depressed inner table shows small central fragment missing. Small tear in dura, through which missing fragment with clots and disorganized brain was expressed by coughing. Usual toilette of cavity by suction and irrigation. Closure of tear in dura with single suture. Closure of scalp as usual in two layers. No drain.

Oct. 19.—Uninterrupted convalescence. Superficial sutures removed on second day; incisions practically invisible (*Fig.* 494). No neurological symptoms. Evacuated.

Subsequent Reports.—Oct. 20, No. 11 General Hospital.—Condition normal. Evacuated to England. Dec. 12, Princess Christian Hospital.—Quite normal: fit for employment. Feb. 14, 1918 (by letter).—Has received discharge: feels perfectly well, but thinks his memory is slightly impaired.



FIGS. 495, 496, 497.—Three views of trepanation block from *Case* 25.

The disposition of the bone fragments in these cases of local depression naturally varies greatly. A fragment may be completely dislodged as in the foregoing, or a sharp spicule may penetrate the dura. If it should have punctured one of the venous sinuses, and the common method of removal, piece by piece, is practised, on withdrawal of the penetrating fragment a sharp hæmorrhage may occur, which is difficult to control owing to the inaccessibility of the bleeding point. This is one reason for strongly advocating the method of block trepanation, for under these circumstances full exposure of the field is immediately secured on tilting up the block, and free access is given to the point of laceration.

FIG. 498.—*Case* 25. Showing wound on first dressing with distant drain.

Case 25.—Sgt. A. R. (Serial No. 80). **Frontal gutter wound; depressed fragment puncturing brain. Recovery.**

Admission, Aug. 27, 1917, 9.30 p.m.—Injured at 2.30 p.m. in front-line attack. Helmet pierced by projectile. Temporary loss of consciousness: walked back to his regimental aid post. Severe headache. No vomiting. Good general condition; fully conscious; pulse 86.

Wound.—A 5-cm. gutter wound, crossing mid-frontal region above supra-orbital ridge. *X*-ray report: "Depressed fracture with indriven fragments."

Neurological Findings.—Negative; no loss of memory; no disorientation.

Operation, Aug. 28, 10 a.m. (20 hours).—Novocain. Excision of gutter wound, disclosing a small depression of external table, with radiating lines of fracture (*Fig.* 495). Trepanation *en bloc*, disclosing a depressed fracture of inner table, with complete mosaic, though one tilted fragment had penetrated dura and brain (*Figs.* 496, 497). Clots and disorganized brain were cleared away by the usual technique. Closure of wound, with single gutta-percha drain, led in from above.

Sept. 2 (*Fig.* 498).—Sutures and drain removed. Temperature still slightly elevated, but wound appears intact. No symptoms. Sept. 9.—Temperature normal; good condition. Evacuated.

Subsequent Reports.—Oct. 24, Bradford War Hospital.—Occasional headache; dizziness on stooping. Invalided. Feb. 17, 1918 (by letter).—In good health; at work.

In contrast to the foregoing, an example may be given of a local fracture possessing quite different characteristics owing to the thicker and less brittle skull. From the outward appearance of the bone a much more serious condition was anticipated than was actually found, otherwise so large a block would not have been removed. The specimen shows well the not uncommon outward dislodgement of plates from the external table as well as indriven inner table—a form of cranial injury characterizing gutter wounds of certain types of skull with a heavy vault.

Fig. 499. *Case* 26. Showing wound before operation.

Case 26.—Pte. A. T. (Serial No. 89). **Frontal gutter wound, with elevation of external and depression of internal tables. Dura punctured. Cerebral contusion. Recovery.**

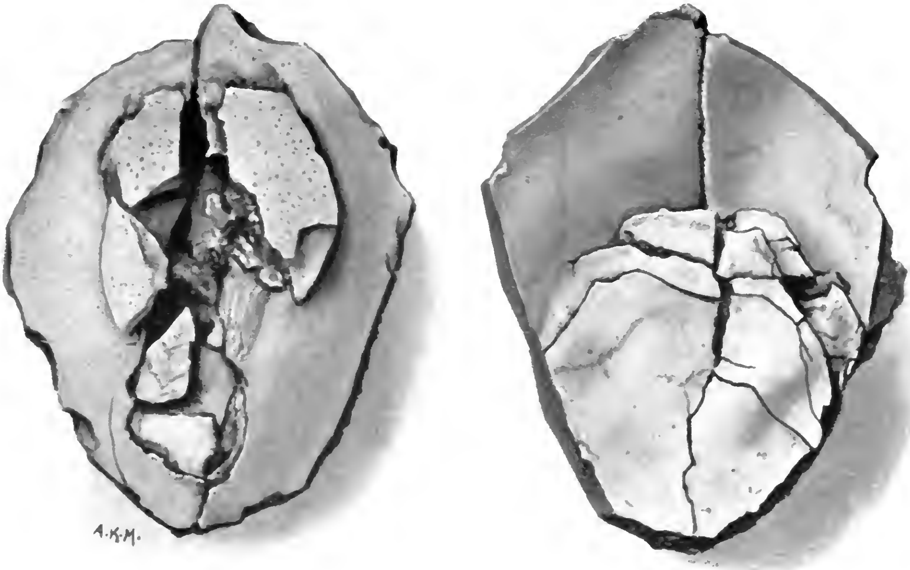
Admission, Aug. 31, 1917, 9.30 p.m.—In a dugout at 4 p.m., without helmet; wounded by shell explosion. Rendered unconscious; roused later, and got back unaided. Resuscitation ward during night; wound Carrelized. Sept. 1, 9 a.m.—Excited; irritable; talking loudly. Pulse 80, good quality. Some mental confusion and disorientation.

Wound.—Gutter type, 5 cm. in length, slightly to left of mid-line at frontal eminence (*Fig.* 499). *X*-ray report: Shows questionable fracture. Complicating wound of right forearm.

Neurological Findings.—Fundi show œdema, with blurring of nasal margins. Mental excitement, otherwise no symptoms of note.

Operation, 10 a.m. (18 hours).—Novocain. Tripod incisions circumscribing scalp wound; flaps reflected, disclosing a gutter in a very thick skull, with lateral elevation of many fragments of external table and radiating fissures (*Fig.* 500).

Wide trepanation *en bloc*: an intact mosaic of depressed inner table: no great dislodgement of fragments (*Fig.* 501); a laceration in the dura, alongside the sinus.



Figs. 500, 501.—*Case* 26. Trepanation block showing behaviour of thick skull to tangential wound.

with a large subdural clot and an area of pulped brain. Through the dural opening the disintegrated and softened brain was removed by suction and irrigation. Dural wound sutured. Scalp sutured in two layers: gutta-percha tissue drain.

Post-operative Results.—Sept. 3.—First dressing (*Fig.* 502): sutures and drain removed: slight discharge of pus (staphylococcus) from site of drain. Carrel-Dakin treatment for next five days. Sept. 20.—Wound healed (*Fig.* 503). No neurological symptoms. Condition excellent. Evacuated.

Fig. 502.—*Case* 26. On first dressing.

Subsequent Reports.—Nov. 30. King George Hospital.—No symptoms except some limitation of fields of vision (?) to right. Dec. 13, Gifford House Auxiliary Hospital (by letter).—Some headaches, otherwise

well; discharged unfit for service. Feb. 15, 1918 (by letter).—In best of health; at work.

Fig. 503.—*Case* 26. On discharge.

Temporal Wounds.—The two temporal cases in this group had no special points of interest, except that in one of them a rivet from the helmet acted as a secondary missile.

Parietal Wounds.—Including wounds of the mid-vertex, there were eight parietal cases. Three of the patients had post-operative Jacksonian attacks, a matter to which we will subsequently return. The history of one of them follows:—

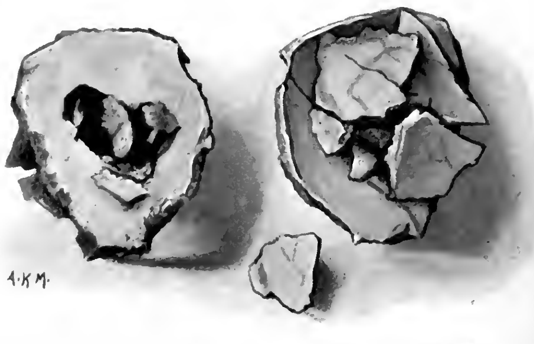
Case 27.—Pte. J. H. T. (Serial No. 163). **Depressed fracture, with dislodged fragment of inner table. Cerebral contusion. Post-operative convulsions. Recovery.**

Admitted, Oct. 3, 1917, 2.30 a.m.—Wounded by a bomb fragment three hours previously. Numbness and weakness of his left arm noticed immediately.

Wound.—Small, penetrating type, 4 cm. to right of median line in plane vertical to auditory meatus. *X*-ray report: "Depressed fracture with indriven bone."

Neurological Findings.—Marked weakness with some loss of common sensation in the left hand; normal sense of position. Slight weakness of left leg. Deep reflexes exaggerated on the left; no clonus; normal plantar responses.

Operation, 11 a.m. (12 hours).—Novocain. Tripod incision. Area of small depressed fracture encircled and elevated, showing depression of inner table, with one fragment of mosaic missing (*Figs.* 504, 505). A tear in the dura disclosed the two large veins (vena anastomotica magna), one of which had been cut across by the dislodged fragment near its point of entrance into the lateral expansion of the sinus. Vein bled profusely on elevating the bone disc; it was secured immediately with a clip. Parietal lobe considerably pulped; usual toilette, with irrigation and suction. The missing bone fragment was detected by the catheter at a depth of 2 cm., and removed. Tear in the dura sutured without freshening its edges; dichloramine-T spray; closure of scalp without drainage.



Figs. 504, 505.—*Case* 27. Bone disc with fragment missing from inner mosaic.

Post-operative Results.—Oct. 6.—Wound without reaction (*Fig.* 506): sutures removed. For the past three days many and persistent Jacksonian attacks in the left arm and hand, where there is now complete loss of power and muscle sense. Weakness also of face and leg. Definite sensory impairment also over left arm and leg. Oct. 9.—General condition excellent, though arm remains paralyzed, and left leg weak. Evacuated.

Subsequent Reports.—Oct. 15, No. 20 General Hospital.—Evacuated to England. Dec. 10, King George Hospital.—No motor or sensory disturbance present. No headaches. Discharged, unfit for service. Jan. 2, 1918 (by letter).—Now back at work; feels no ill effects from his injury.

Fig. 506.—*Case* 27. Tripod incisions on third day.

It is quite probable, in explanation of the post-operative increase in the paralyses in this case, that some bleeding occurred, with refilling of the cavity. Such an accident, however, is rare, even in these parasinoidal cases, particularly when they have been operated upon under a local anæsthetic. When they have been given inhalation narcosis, vomiting may so increase venous tension as to start up bleeding which appeared to have been checked.

In one other patient (Serial No. 75) with a lesion quite similar to the foregoing, Jacksonian attacks also occurred. The case furnishes an interesting example of a direct hit on a helmet (*Fig.* 507) where the skull escaped with a slightly depressed inner table (*Figs.* 508, 509), a lacerated dura, and considerable pulping of the parietal lobe. The wound was closed as usual without drainage, and the patient did well, but for three or four days after the operation there was an almost continuous twitching and spasm of the left arm. Whenever any voluntary effort was made to move the hand, a typical Jacksonian attack would originate in the thumb and extend up the arm to the shoulder. The attacks subsided, and there was no recurrence; this fortunately is the usual history of these early post-traumatic examples of focal epilepsy.

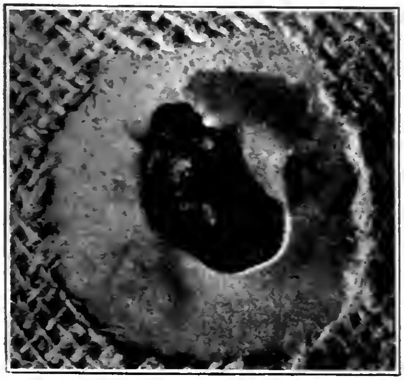
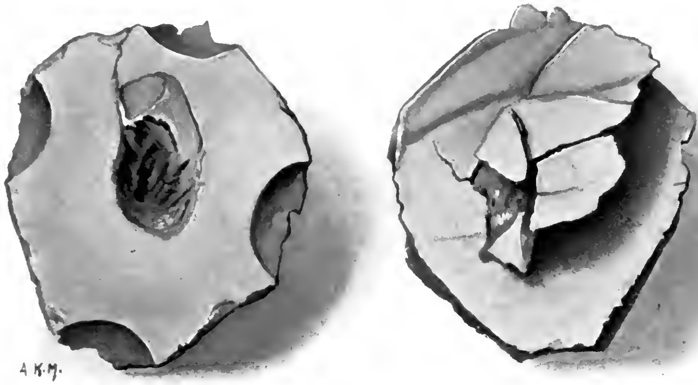


Fig. 507.—Serial No. 75. Penetrating injury of helmet (natural size). Cf. *Figs.* 508, 509.

The wound in two of the parietal cases lay directly over the longitudinal sinus in the mid-vertex; one of them (Serial No. 58) was without

symptoms—no demonstrable spasticity—though the dura was lacerated and the hemisphere contused. Momentary active hæmorrhage from the sinus followed elevation of the bone disc, but the bleeding was easily checked by a muscle graft, and a good recovery followed.



FIGS. 508, 509.—Serial No. 75. Slightly depressed fracture (cf. helmet, *Fig.* 507).

The following case showed symptoms more characteristic of a lesion in this neighbourhood. The operation—one early in the series, and under a general anæsthetic—was imperfectly carried out, and a late abscess developed.

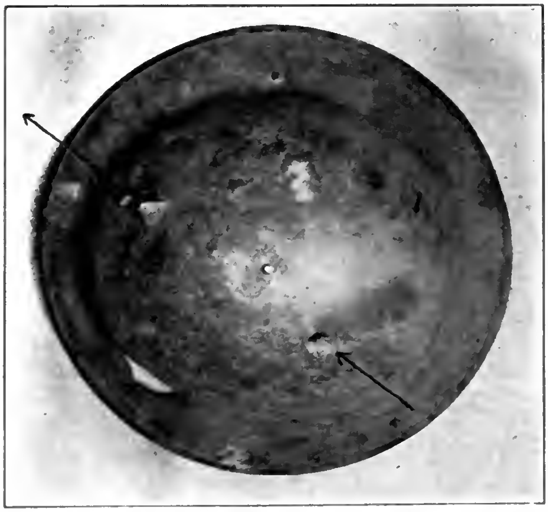


FIG. 510.—*Case* 28. Perforation of helmet by rifle ball, producing seton wound of vertex.

Case 28.—Pte. T. B. (Serial No. 25). **Seton wound of vertex. Hemiparesis, with focal epilepsy. Imperfect operation. Late abscess. Recovery.**

Admission, Aug. 2, 1917, 11 a.m.—Wounded at 8 a.m. on the previous day by a sniper, the ball perforating his helmet (*Fig.* 510). No loss of consciousness, nor headache, but his left hand and foot immediately felt numb and weak. About twelve hours later he began to have Jacksonian seizures in his left side, originating in the leg and lasting four or five minutes, without loss of consciousness.

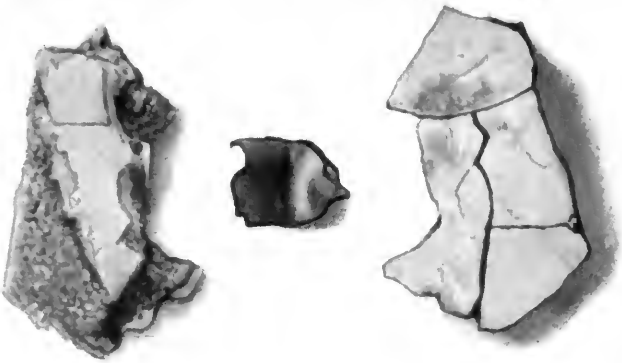
General Condition.—Conscious; rational; pulse 88.

Wound.—Of entrance and exit, 5 cm. apart, in the mid-vertex, the exit wound being slightly to the right of the midline. *X*-ray report: "Depressed fracture of mid-vertex, with radiating fissure in skull running posteriorly. Superficial foreign body."

Neurological Findings.—Left hemiplegia, with extreme spasticity and rigidity of lower extremity, the arm being somewhat less involved. Right leg weak and

somewhat rigid. Deep reflexes exaggerated both right and left, with ankle clonus, less well sustained on the right; positive Babinski both right and left. Deep reflexes of arms exaggerated on left, normal on right. Frequent focal seizures, which begin in muscles of the left thigh, and cause powerful and painful contractions of the leg in adduction and flexion, with clonic jerking. By the time of his operation he was unable to move his left arm or leg, and slight weakness in the left face was apparent.

Operation, 2 p.m. (30 hours).—Ether. Scalp wound excised, exposing a deep gutter fracture extending slightly to the right from mid-line; a portion of the jacket of the rifle ball wedged in the fracture; bone much fragmented; one large plate of depressed bone consisting of both tables was lifted out from over the sinus without causing bleeding (*Figs.* 511, 512). The underlying dura was torn and the brain



Figs. 511, 512.—*Case* 28. Outer (left) and inner (right) surface of single central depressed fragment; also bit of jacket of rifle ball removed from gutter.

greatly pulped; clots and disorganized cerebral tissue were expressed largely by pressure on the surrounding dura; no attempt made to thoroughly empty cavity. Closure by plastic, with lateral drain.

Post-operative Results.—Aug. 5.—Repeated, though lessening, Jacksonian attacks occurred for past three days; some movement has returned in the leg. Temperature practically normal (*Fig.* 513), despite a right pleurisy. Aug. 9.—Wound infected (staphylococcus): partly opened and Carrelized. Aug. 13.—Wound still discharging. General condition excellent. No fungus. Right side remains practically paralyzed, without sensory loss. Evacuated.

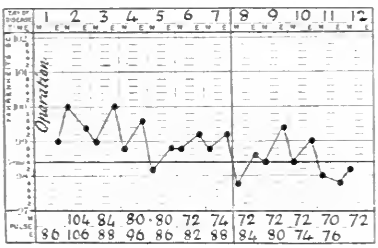


Fig. 513.—*Case* 28. Temperature chart.

Subsequent Reports.—Sept. 8. No. 11 General Hospital.—Wound practically healed: small sinus. Neurological condition unchanged. Evacuated to England. Dec. 30. King George Hospital.—Abscess developed, and was opened Nov. 1. Good recovery. At present regaining movements in shoulder and arm. General condition good. No further Jacksonian attacks. Jan. 23.—Up and very much improved: arm and leg gaining strength.

The Fatal Cases.—Two occurred in this group—both parietal cases, both early in the series.

Case 29.—Gnr. A. W. B. (Serial No. 4).

July 25, 1917.—Serious condition from multiple wounds: penetrating wound

of thorax: fracture of spine, with paraplegia; gutter wound of left parietal, with contralateral symptoms in arm.

Operation.—Ether. Hurried repair of all three injuries. Depressed fracture of skull; dura penetrated; severe contusion of parietal lobe. Death on eighth day.

Autopsy.—Meningitis; double bronchopneumonia; fracture of spine.

FIG. 514.—*Case* 30. 23·42-grm. shell fragment (natural size) of a 5·9 shell.

Case 30.—Sgt. E. B. (Serial No. 44).

Aug. 11, 1917.—Lying-out case, twenty-four hours. A ragged infected right parietal wound; a large shell fragment (*Fig.* 514) wedged in a depressed fracture; dura lacerated.

Imperfect operation, under ether; flap method; incomplete toilette of greatly contused parietal lobe. Wound infection (*B. perfringens*); fungus cerebri. Death third day.

Autopsy.—General meningitis; encephalitis.

Group IV.—**FRACTURES WITH DISLODGED BONE FRAGMENTS PENETRATING BRAIN, USUALLY WITH EXTRUSION OF CEREBRAL SUBSTANCE.**

Here we come to a more serious type of injury, one in which fragments, often of both tables—contaminated fragments consequently—are widely indriven. There is apt to be a considerable defect in the skull, through which cerebral substance extrudes, adding greatly to the probability of infection.*

The external wound accompanying this type of lesion is usually of the tangential (gutter) variety, though it may be produced by a direct blow from an indented helmet, or the helmet may be penetrated and the missile be found in the superficial wound or lodged in the bone. It will be seen that *far the larger number of these wounds occur over the parietal area* or its junction with frontal or occipital fields.

All told, 39 cases fall in this category. The scalp wounds (often the cranial wound as well) were tangential in 25 cases, ragged, more or less circular wounds in 8, of the small penetrating type in 5, and *en séton* in 1. An extrusion of cerebral substance from the wound, or direct exposure of the brain, was recorded in all but 12 of the case-histories.

The wound was over the parietal area in 27 of the 39 cases (including parieto-frontal 6, parieto-occipital 3, and mid-vertex 5), over the occipital area in 8, frontal area in 3. It is to be noted, in contrast to the anatomical site of the wounds with a lodged projectile (*Group V*), that there were no temporal or occipito-cerebellar wounds.

As might be surmised from this description of these injuries, the exact *nature of the missile* producing them can only be conjectured in the larger number of the cases. Moreover, men with these more serious injuries had no

* There may, of course, be considerable overlapping of these groups, and such a case as that described earlier in the paper (*Figs.* 461–465), with fragments from the inner table showered well into the hemisphere though the external table remained intact, would hardly fall in this group so far as risks of infection are concerned, though it would naturally be placed here on the basis of the accompanying cerebral injury.

interest in bringing in their damaged helmets, and the stuporous condition of 12 of them on admission precluded any history whatsoever. In 19 cases there was a definite history of the helmet being worn; in 5 it was not worn, two of these being bombing accidents. The missile was identified as a shell fragment in 5 cases, shrapnel ball in 1, grenade in 3. One officer felt confident that a rifle ball had penetrated his helmet, and four others were under the impression they had been hit by machine-gun bullets. It is the type of injury one would expect from a rifle ball penetrating the helmet, but in the confusion of a modern battle a wounded man can hardly be expected to know what has hit him, and unless a fragment has lodged, one can only conjecture what the missile may have been.

In brief, it appears that cerebral injuries of this variety, with indriven bone fragments and escape of bruised cerebral substance, are commonly produced by tangential wounds over the thicker portions of the skull, particularly of the parietal regions. The helmet in all likelihood has been perforated in most cases; the wounds are almost always single; and it is the type of injury that one would expect from a rifle or machine-gun bullet. By just what mechanism the fragments of bone are driven at right angles to the line of flight of the projectile is not entirely clear.

The wounds in most cases are so similar and so characteristic that there is little occasion for subdivisions, though there are two which must be recognized as important: (*a*) *Those in which the fragments lie short of the ventricle* (25 cases); (*b*) *Those in which they have opened the ventricle* (14 cases). The mechanism of the production of the injury is of course the same in both instances, but the distinction is based, as is the distinction between cases with an open or closed dura, more on the all-important factor of potential infection, than upon the rule that the deeper the fragment the more severe the injury.

Taking the group as a whole, there were 12 deaths in the 39 cases (mortality 30·7 per cent), but the far greater seriousness of the ventricle cases over the others can be best shown by separating these types. In 25 examples of the (*a*) type there were 6 fatalities (24 per cent); in 14 examples of the (*b*) type, with the ventricle penetrated, there were 6 fatalities (42·8 per cent).

Inasmuch as one object of this report is to emphasize the effects of the injury upon the brain rather than its effects on the skull, the further discussion of the ventricular cases will be reserved for a later section (*Group VI*), in which they have been placed.

As has been pointed out, the majority of these wounds lie over the parietal vertex, and consequently many are accompanied by grades of what Sargent and Holmes have called the longitudinal-sinus syndrome. This, as I interpret it, is a symptom-complex which indicates a contusion of the vertex in which the mesial edges of both hemispheres participate, leading to a bilateral spastic paralysis of the lower extremities, with possible involvement of one or both arms. The condition is one which has its counterpart in the traumatic spastic paralysis of child-birth—the so-called Little's disease. Occasionally one finds thrombosis of the sinus or entering vessels, but I feel very doubtful as to whether these vascular lesions are the actual cause of the symptoms. The syndrome certainly occurs when there is no evidence

of thrombosis, and the bilateral contusion which is almost inevitably present would seem to be a sufficient explanation.

One interesting feature of these cases is the progressive nature of the symptoms recognized by the victim of the injury, who, after return of consciousness, is aware of weakness in one leg, or leg and arm, and finally the other leg; or in extreme cases both leg and arm become involved. Primary weakness and numbness is succeeded by paralysis and spasticity, with more or less adductor spasm.

The three following cases illustrate severe grades of this syndrome.

Case 31.—Pte. R. W. T. (Serial No. 18). **Transverse gutter injury of mid-cranial vault, with sinus injury and indriven fragments. 'Longitudinal-sinus syndrome.' Operation.**

Admitted Oct. 9, 1917, 8 a.m.—Wounded in early morning of preceding day by shell fragment which traversed helmet. Unconscious for some time. On regaining consciousness found he could not walk; helped into a shell hole and remained all day. During this time he observed that his legs were getting rigid, and also that his arms were beginning to feel stiff and numb. Rescued by bearers late in the evening.

FIG. 515.—*Case* 31. Gutter wound across vertex: sinus syndrome.

General Condition.—Conscious; rational; pulse 100. No shock.

Wound.—Large transverse gutter type, measuring 10 by 5 cm., in posterior parietal region, somewhat more to right side (*Fig.* 515). *X*-ray report: "Fissured fracture of vertex. Bone-fragments indriven. No missile."

Neurological Findings.—Weakness, numbness, and spasticity of all four extremities, more marked in legs, particularly the left. Face not involved. Considerable lowering of sensitivity to pain over legs, though thermal sense fairly well preserved. Some sensory loss also on arms. Definite loss of muscle sense with astereognosis in left hand. Reflexes greatly exaggerated throughout, with bilateral knee and ankle clonus well sustained. A positive, slow, Babinski response on left; equivocal on right, where response is very active. Plantar stimulation on left leads to drawing up of right foot, with flexion of ankle. Vasomotor: left leg and foot cold; right, warm and sweating. A similar condition, though less marked, in the arms.

Operation, 4.30 p.m. (*circa* 34 hours).—Novocain. A long transverse incision, like an autopsy incision, circumscribing the dirty scalp wound. Exposure of an opening in the external table 2·5 cm. in length (*Fig.* 516), extending to the interparietal suture; radiating fissures pass in a coronal direction. Trepanation *en bloc*, disclosing a defect in the dura 2 by 1·5 cm., to the side of the sinus. Fragments of bone and disorganized brain were extruding. On the inner surface of the block were a few loosely attached spicules (*Fig.* 517); other fragments completely separated were carefully withdrawn. The dislodgement of one spicule which had penetrated the lateral wall of the sinus was followed by a momentary profuse bleeding; checked by the placement of three silver clips on the margin of the sinus. The right parietal lobe was greatly pulped. The track made by the indriven fragments was sucked and irrigated by the usual catheter method until the tension completely

subsided. From the bottom of the track at a depth of 5 cm. eight fragments of inner table shown by *x* rays were recovered. A small amount of dichloramine-T

Figs. 516, 517.—*Case* 31. Bone block showing: *Left.*—Interparietal suture and fissures radiating from gutter; *Right.*—A few fragments of internal table still attached.

was left in the track; the transverse incision was closed in layers, with a single drain of protective tissue let in through a puncture opening (cf. *Fig.* 518).

Post-operative Course.—Oct. 12.—Sutures and drain removed. No untoward symptoms. Oct. 14.—Spasticity of legs subsiding, especially of right, where considerable movement is present. Astereognosis of left arm persists. Evacuated (fifth day). (*Fig.* 518.)

Fig. 518.—*Case* 31. Wound on evacuation; fifth day.

Subsequent Reports.—Oct. 16. No. 11 General Hospital.—"Considerable headache on admission, with choked disc of 1 D. Wound clean. Loss of touch, pain, and temperature sense of all extremities. Left arm weak at shoulder and slightly spastic. Right arm about two-thirds normal. Legs slightly spastic and weak—about one-third normal. Superficial abdominal reflexes absent on left. Deep reflexes bilaterally exaggerated." Dec. 26. Stepping Hill Hospital.—"Progressing favourably; general health good. Arms and right leg largely restored; left leg has good hip, feeble knee, and absent ankle movement, with some dulling of sensation Deep reflexes + + ."

Feb. 15, 1918 (by letter).—"Still in hospital and improving; left leg still weak, right fairly strong."

It is of course ideal in a case of this sort to close the scalp, but if there has been an obviously imperfect toilette of the pulped brain area, less risk is run by leaving the wound open. Under certain circumstances, therefore, it may be unwise to cover the defect, as in the following case—occasionally it is impossible to do so, as in the succeeding one.

Case 32.—Rfm. W. M. (Serial No. 120). **Gutter wound of vertex, with fungus. 'Longitudinal-sinus syndrome.' Incomplete wound closure, with direct treatment of hernia. Recovery, with residual paralysis.**

Admitted Sept. 21, 1917, 1 a.m.—Wounded on preceding day about 5 a.m. Lay in shell hole all day, unable to crawl back owing to weakness of right side. Severe headache and vomiting. Brought in by bearers.

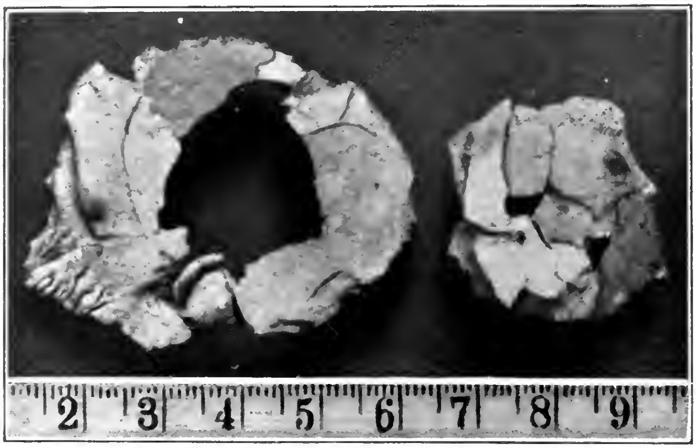


FIG. 519.—*Case* 32. Showing: *Left.*—Much broken up skull: *Right.*—Indriven bone fragments, six in number. Both specimens were pieced together after removal.

General Condition (after 8 hours in resuscitation ward).—Fully conscious. No mental disturbance. Pulse 72. Body warm. Fundi normal.

Neurological Findings.—Complete spastic paralysis of right leg and arm. Face uninvolved. Partial paralysis, with some spasticity, of left leg. Left arm uninvolved. Deep reflexes exaggerated, with bilateral clonus, less well sustained on the left. Positive bilateral Babinski reflex.

Wound.—Of gutter type; slightly to the left of the mid-line of vault. Wound edges infected; a foul-smelling fungus cerebri full of hair and fragments of bone. *X*-ray report: "Fracture, with indriven bone. No missile."

Operation, 10 a.m. (28 hours).—Novocain. Scalp wound encircled and excised. Incisions prolonged in *fleur-de-lys* fashion (cf. *Fig.* 520) in preparation for plastic closure. The flaps were reflected, disclosing an opening in the skull 2 by 2 cm. in diameter, with protruding fungus and many radiating lines of fracture. Skull thin, brittle, with little diploë. Removal *en bloc* of bony area (*Fig.* 519). Pulped area in left upper paracentral region thoroughly cleansed by suction and irrigation; removal of all fragments of indriven bone (*Fig.* 519). Owing to obvious local infection, wound was incompletely closed, leaving an opening directly over the fungus; treated with dichloramine-T.

Subsequent Course.—A small fungus developed, which was dressed daily and treated with dichloramine-T. Oct. 4.—Temporary cerebrospinal-fluid leak, which persisted for forty-eight hours. The small fungus, which never protruded above the level of the scalp, finally subsided, and began to heal over. Patient's general condition remained excellent throughout, and the temperature after the first day was normal (*Fig.* 521). No alteration occurred in the spastic paralyses, and voluntary movement was practically confined to his left arm. Evacuated Oct. 14 (twenty-third day).

Subsequent Reports.—Oct. 16. No. 11 General Hospital.—Condition good. Immediately evacuated to U.K. Dec. 27 (letter from patient, at King George Hospital, written with left hand).—Up on couch, but unable to stand as yet. Jan. 10, 1918 (report from the M. O.).—Wound healed; no headaches; mentality normal. Right arm and leg continue spastic, though considerable return of all movement except at ankle. Chief residual weakness in right hand and foot. Deep reflexes remain + + . Slow though progressive improvement. Feb. 2 (by letter).—Steady progress; taking walking lessons.

Fig. 520.—Fleur-de-lys incisions; partial closure; fungus left in centre.

Attention may be called to the structure of the cranial vault in the foregoing case; it was comparatively thin and fragile, and had broken into many small pieces like a piece of china; this is in marked contrast to the character of the vault in *Case* 26 (*Fig.* 502).

In the next case, another of this same clinical type, it was impossible to close the wound, though the attempt was made to do so.

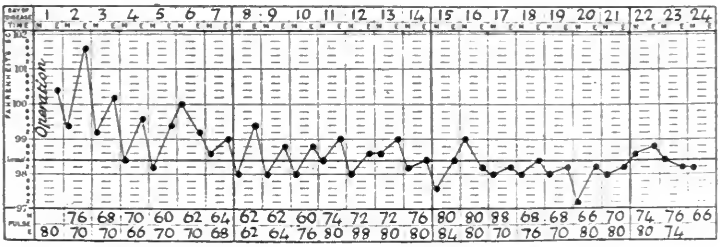


Fig. 521.—*Case* 32. Chart showing regular temperature despite fungus and cerebro-spinal-fluid leak.

Case 33.—Pte. T. T. (Serial No. 180). **Gutter wound of vertex; cerebral herniation; 'longitudinal-sinus syndrome.' Operation, with removal of indriven bone fragments. Scalp wound not closable.**

Admitted Oct. 10, 1917, 1.20 p.m.—Wounded 6 a.m. on previous day. Was wearing helmet. Temporarily unconscious. Lay in shell hole all day. Immediate weakness of entire right side, and gradual of left leg during the course of the day. Brought in by bearers after twenty-four hours. Both legs and right arm have become increasingly stiff, but was able to move the left leg until this morning.

General Condition.—Conscious; rational; no mental symptoms. Pulse 80. Body warm.

Neurological Findings.—Legs rigid, with marked adductor spasm; completely paralyzed. Considerable hypæsthesia, but can distinguish between sharp and dull stimuli, though less well on right than left. Right arm also completely paralyzed and stiff, with considerable sensory loss to pain and temperature. No recognition

of objects placed in hand. Deep reflexes greatly exaggerated throughout, but no clonus elicited. Bilateral dorsal toe-response to plantar stroking.

Wound.—A very wide lacerated gutter wound slightly to the left of the mid-line at mid-vertex. *X*-ray report: "Depressed fracture with indriven bone. No missile."

Operation, 10 p.m. (after 40 hours).—Novocain. Excision of dirty scalp wound with gaping infected edges. Area of involved bone removed *en bloc* from over sinus, disclosing a tear in dura to margin of sinus. Many spicules and plates of inner table removed from about 5 cm. deep in left hemisphere. Devitalized brain area removed by irrigation and suction. A large anastomotic vein, which was uninjured and unthrombosed, bridged over the gap. This was doubly ligated. A large clean cavity was left in the hemisphere. An attempt to close the defect by an extensive plastic was abandoned, owing to the dense and immobile character of the patient's scalp, which could not be easily shifted. Incisions sutured. Protective dressing directly over wound in dura with dichloramine-T.

Post-operative Course.—Oct. 22.—Condition has remained excellent, with normal temperature, despite development of a small fungus. Continued dichloramine-T dressings. Fairly rapid return of movement in left leg. Right side remains paralyzed. Oct. 29.—Some movement returning in right leg at hip and knee, and in right arm at elbow. Deep reflexes remain hyperactive, with clonus on the right. Nov. 16.—Condition progressively improving. Fungus clean. Evacuated.

Subsequent Reports.—Nov. 18, No. 14 General Hospital.—Picric acid dressing. Evacuated immediately to England. Jan. 10, 1918 (by letter from King George Hospital).—Still in bed; fungus not entirely healed; right arm and leg still weak and stiff. Feb. 22 (by letter).—Wound healed; regaining movement in arm and leg.

Another parietal injury which falls in this group was as follows. The wound was of the direct rather than the more common tangential variety, and some interest attaches to the behaviour of the fragments. Large scales of the broken inner table, though fully detached, yet remained adherent to the dura, and through and between them a single fragment of outer table was deeply indriven (cf. *Figs.* 522, 523, 524). A similar occurrence will be met with in a case in a subsequent section (*Group VI, Fig.* 150).

Case 34.—Pte. W. G. T. (Serial No. 74). **Multiple wounds. Depressed fracture; cerebral extrusion; contralateral monoplegia. Operation; removal of deep bone fragments. Recovery.**

Admission, Aug. 22, 1917, 2 p.m.—Wounded by shell at 6 a.m.; apparently no loss of consciousness; walked unaided to aid post. History obtained with difficulty, owing to speech defect.

Condition.—Good; rational; pulse normal.

Wounds.—(1) Lacerated wound, arrow-head in shape, over the left parietal eminence near mid-line; depressed fracture of skull; extrusion of cerebral substance. *X* rays show indriven bone with minute foreign particles. (2, 3) Penetrating wounds of left shoulder and left knee.

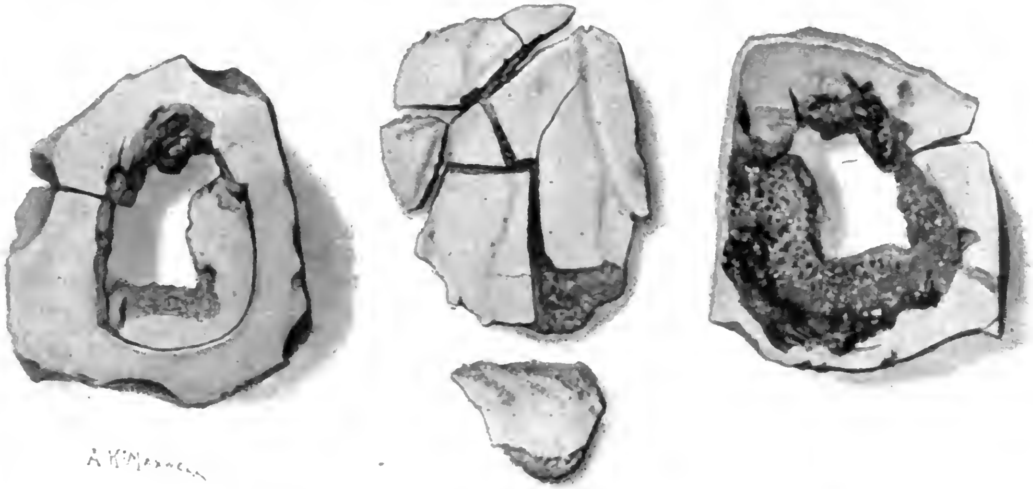
Neurological Findings.—Slight paraphasia: gets words with some hesitation and stammering. Slight weakness of right face; complete paralysis of arm; no apparent weakness of leg. No demonstrable sensory loss; muscle sense normal. Deep reflexes active, equal; without clonus.

Operation, 10 p.m. (14 hours).—Novocain. Tripod incision encircling wound, disclosing depressed fracture (*Fig.* 522), with absence of bone substance and a wide radiating fissure. Trepanation *en bloc*, showing (*Fig.* 523) wide fracture of inner table, with detachment of five large pieces, two of which, together with a fragment of external table, were driven deeply into the brain through a tear (2 by 1·5 cm.) in the dura. Area of brain greatly pulped; thorough toilette. Closure of scalp wound, with single gutta-percha drain. Repair of wound of shoulder and knee.

Post-operative Course.—Aug. 28.—Movement beginning to return in right hand

and arm. Paraphasia practically disappeared. Aug. 31.—Wound perfect; temperature normal. Evacuated.

Subsequent Reports.—Sept. 2, No. 10 General Hospital.—Condition practically normal. Evacuated to England. Oct. 27, 1st Southern Hospital, Birmingham.—Condition normal. Free from subjective symptoms. Slight weakness of right arm. Boarded as permanently unfit. Jan. 26, 1918 (by letter).—No residual symptoms whatsoever; no headaches: expects to resume occupation.



FIGS. 522, 523, 524.—*Case* 34. *Left.*—External table with defect in depression and fissures; *Right.*—Inner table showing marked loss of substance; *Centre.*—Mosaic of fragments of internal table pieced after removal; *Below.*—Single indriven fragment of external table.

An example of a more posterior wound of this same type, with injury of the occipital lobe, follows. The patient had been lying out, and in the face of an infection, possibly too great risks were taken in closing the wound without a drain. Had the presence of gas bacilli on the indriven bone fragments been foretold, drainage would have doubtless been employed. Examples of disaster from closure under these circumstances were not infrequent in the early series, particularly before we came to the routine employment of dichloramine-T in these gas-suspected wounds.

Case 35.—L.-Cpl. W. J. W. (Serial No. 49). **Right parieto-occipital wound, with herniating brain. Dural penetration by indriven bone fragments, showing B. perfringens on culture. Left homonymous hemianopsia.**

Admission, Aug. 14, 1917, 6.15 p.m.—History obscure: patient disoriented. Thinks he was wounded two days ago going over his parapet; wearing helmet. Remembers being brought in by stretcher bearers.

General Condition.—Somewhat stuporous, but can be roused to answer questions. Pulse 60. Severe headache; vomiting. Eyes practically closed by ecchymosis and œdema of lids.

Wound.—A circular, ragged, bad-smelling wound about 3 cm. in diameter over right posterior parietal region. Cerebral substance extruding. *X*-ray report: "Fracture with cranial defect and five indriven bone fragments" (*Fig.* 525).

Neurological Findings.—Right pupil larger than left. Fundi show low grade of papillœdema with obscuration of disc margins. No paralyses detected. Impossible to test for hemianopsia. Normal plantar responses. No abdominal reflexes.

Operation, 8 p.m. (*circa* 48 hours).—Novocain. Excision of scalp wound. Block trepanation, disclosing laceration of dura about 2 cm. diameter, and fungus. Suction and irrigation of track, with removal of the bone fragments from depths of 5 and 6 cm. Complete relief of pressure. Fungating portion of brain bluntly excised. Tripod scalp incisions closed in layers; no drainage.

Fig. 525.—*Case* 35. *X*-ray photograph, showing square defect and five indriven fragments.

Smears and cultures (Capt. Leitch) from a deep bone fragment show bacilli of the perfringens type.

Post-operative Course.—Aug. 16.—Condition excellent. Sharply-cut left homonymous hemianopsia demonstrable. Patient much more alert. Aug. 18.—Normal healing; sutures removed (*Fig.* 526). Still some slight headache. Subconjunctival ecchymoses have appeared. Some continued elevation of temperature (*Fig.* 527), but wound shows no tension. Sept. 5.—General condition excellent. Wound perfectly solid and without tension. Subconjunctival ecchymosis persists, also left homonymous hemianopsia. Evacuated.

Subsequent Reports.—Sept. 12, No. 1 Canadian Hospital.—Some cephalalgia. Wound healed. Evacuated. Jan. 1, 1918, Northumberland War Hospital (by letter).—Condition remains good except for persistence of hemianopsia and occasional headache; up and about; being retained for bone-grafting operation. Jan. 18 (by letter).—Final decision not to operate. Has received his discharge; feels well, and expects to return to his business. Feb. 14.—Doing well, but annoyed by pulsation in defect after exertion.

Fig. 526.—*Case* 35. Patient on fourth day.

The following, another parietal lesion, is an example of a direct rather than a tangential hit, with lodgement of the missile in the skull. Under these circumstances the showering of cranial fragments into the cerebrum is easily understood.

The case is an example also of a double cranial injury. The auro-petrosal wound might easily have been the more serious of the two had the dura not

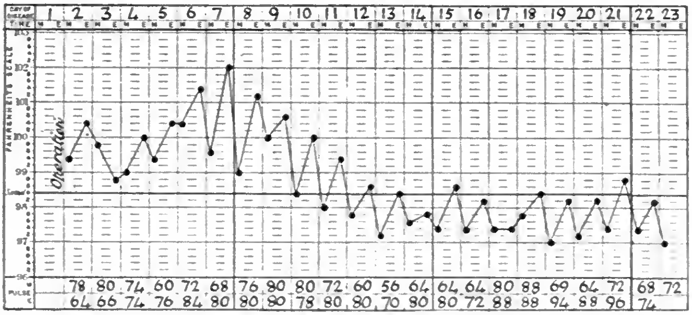


FIG. 527.—*Case* 35. Chart showing irregular temperature though wound remained intact.

remained intact. Had it been torn, the case would properly have fallen in the group of far more serious lesions to be considered later on (*Group VII*).

Case 36.—Pte. G. A. A. (Serial No. 70). **Multiple shrapnel wounds. Superficial lodgement of ball in parietal bone, with fragments projected into brain. Second ball in petrous bone, with intact dura. Recovery.**

Admission, Aug. 20, 1917, 10 a.m.—Probably wounded in early morning attack. No reliable details elicited.

General Condition.—Semi-conscious: can be roused with difficulty; responds vaguely to questions. Is somewhat disoriented. Pulse 60.

Wounds.—Three circular scalp wounds with ragged edges, apparently penetrating: (1) Over left parietal eminence 3 cm. from mid-line; (2) Over left mastoid; (3) Just anterior to the attachment of the pinna: also (4) A perforating wound of right deltoid. *X* rays show two shrapnel balls, one in the parietal bone with indriven fragments, a second in the right petrous bone in line with the auditory canal.

Neurological Findings.—Persistent conjugate deviation of head and eyes to the right. Can be induced momentarily to turn eyes to left; the movement elicits nystagmus. Apparently complete left hemiplegia. Sensory tests unreliable. Deep reflexes not obtained on left; sluggish on right. Normal plantar response on right; sluggish on left.

Operation, 6 p.m. (*circa* 12 hours).—Novocain.

Temporal wounds: A curvilinear incision made incorporating the wounds before and behind left ear; downward reflexion of flap. Wound over mastoid non-penetrating. Under anterior wound is a badly fractured petrous bone, with iron shrapnel ball lodged deeply in the region of the middle ear. The ball was removed, together with many fragments of petrous bone (*Fig.* 528) and pieces of helmet lining. Dura contused, but intact. Closure of flap, with direct drainage through unexcised original wounds.

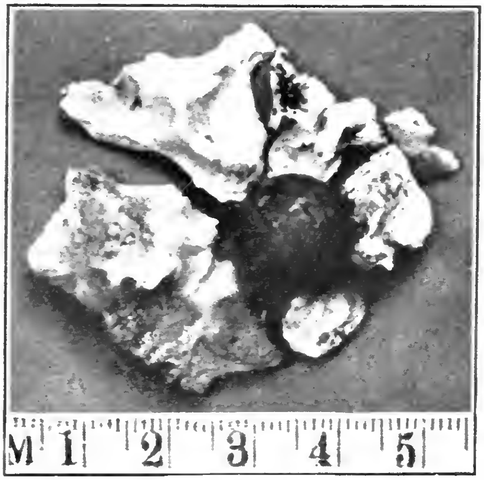


FIG. 528. *Case* 36. Ball from petrous bone with dislodged fragments.

Parietal wound : Tripod incisions ; ball found lodged in bone (*Fig.* 529), with protrusion of cerebral substance alongside it. Trepanation *en bloc* ; practically all fragments of inner table detached and showered through a laceration in the dura (*Fig.* 530). On dislodging some superficial fragments, much clot and disorganized brain extruded itself. Other fragments were removed from a depth of 5 cm. at the bottom of the pulped area. Careful toilette of cavity ; closure, with direct gutta-percha drain.

Shoulder wound : Excision of lacerated muscle in track ; Carrel-Dakin treatment.

Post-operative Course.—Aug. 22.—Wounds look well ; sutures removed. Some return of movement in left side, which is still very weak. Persisting conjugate

FIGS. 529 530, 531.—*Case* 36. Ball lodged in parietal bone : indriven fragments recovered : one fragment attached to inner surface of block.

deviation of eyes to right ; movement to left brings out nystagmus. Aug. 29.—Wounds practically healed. Moves left leg well ; arm remains paralyzed. Still some nystagmus to the left. Right deafness persists. Evacuated, though some slowing of pulse and somewhat irregular temperature (*Fig.* 532).

Subsequent Reports.—Oct. 3 (by letter from Lord Derby War Hospital).—Was evacuated to England Sept. 9. Wound perfectly healed, now up in wheeled chair. Jan. 10, 1918.—Left leg normal ; free movements of left arm and a fairly good grasp with the left hand, which shows daily improvement. Right ear deaf. Jan. 18.—Has had an aluminium plate, 3 in. by 2 in., inserted by operation over the defect ; dura torn at operation ; two epileptiform seizures followed. Feb. 15.—Up again, and doing well after four weeks in bed following operation ; arm improving.

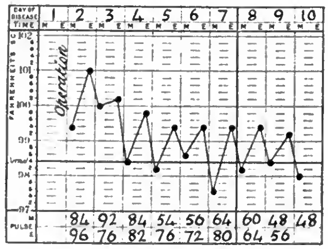


FIG. 532.—*Case* 36. Chart showing slight irregularities though wound remained intact.

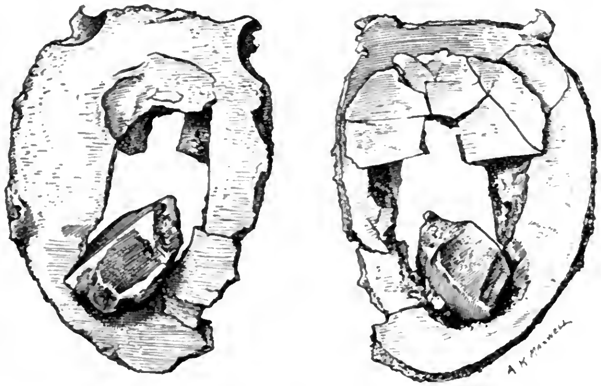
The foregoing story shows that not only gutter wounds, but also direct or oblique impacts with lodgement of the missile, may produce a showering of bone fragments. There was one other case in the series (Serial No. 112) with a parietal wound very similar to the above, in which an 8-grm. shell fragment, showing a burnished surface from helmet perforation, was wedged in the broken skull (*Figs.* 533, 534). The man was discharged on the fifth day with perfect wound healing, and has made a good final recovery.

In the following case there were two cranial wounds of different types—

one a gutter wound with indriven bone fragments, the other a small penetrating wound with intracerebral lodgement of the projectile. The former was regarded as the more serious, and the penetrating wound was treated conservatively and allowed to pursue its own course.

Case 37.—Bdr. W. C. (Serial No. 176). **Multiple wounds. Two cranio-cerebral; gutter wound of left parietal, operated upon; penetrating wound of frontal, no operation. Recovery.**

Admission, Oct. 9, 1917, 11.15 a.m.—Wounded in back area at midnight, while asleep without a helmet. No loss of consciousness; immediate numbness of hand and arm: walked short distance with help; arrived in good condition.



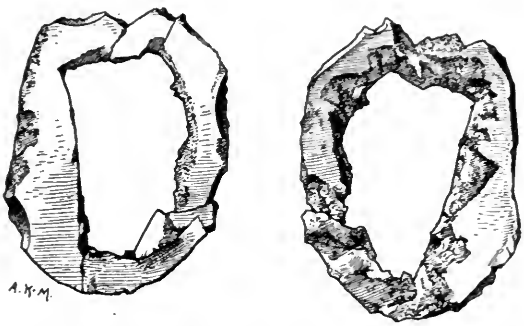
Figs. 533, 534.—Example of lodged shell fragment: lodged in an oblique gutter wound.

Wounds.—(1) Gutter type, of right posterior parietal; extruding brain; (2) Penetrating type, through right frontal sinus; (3) Penetrating right cheek, with paralysis of lower facial. *X*-ray report: "Depressed fracture of right parietal, with indriven bone; fracture of frontal, with small metal fragment 5 cm. in brain."

Neurological Findings.—Weakness of left face and arm; loss of muscle sense; astereognosis. Deep reflexes + +; equal.

Operation, 2 p.m. (14 hours).—Novocain.

1. Tripod incisions encircling gutter wound. Block trepanation of small depressed gutter fracture (*Fig.* 535) with very dirty fungus. Inner table entirely dislodged (*Fig.* 536), with showered fragments. Bleeding artery on cortex, secured by clip. Usual toilette of pulped track. Dichloramine-T. Tear in dura approximated with single suture. Scalp closed with no drain.



Figs. 535, 536.—*Case* 37. Small gutter fracture in thin skull; complete dislodgement of fragments.

2. Dichloramine-T treatment of track of frontal wound, which penetrated frontal sinus: no operation.

3. Wound of cheek, penetrating parotid: projectile lodged near angle of jaw. Counter-opening made: through-and-through gutta-percha drain (*Fig.* 537).

Post-operative Course.—No fever; wounds healed well (*Fig.* 538). Rapid improvement in palsy of opposite arm. Evacuated Oct. 14 (fifth day).

Subsequent Reports.—Oct. 19, No. 13 General Hospital.—Evacuated to England, Dec. 7, Oakbank War Hospital.—Paralysis of lower branches of right facial. Slight loss of power in left hand; improving. Evacuated to Auxiliary Hospital. Feb. 15, 1918 (by letter).—Back in the army signal section since Jan. 1: complains of headaches.

Mention has been already made of the fact that the occipital cases have in some respects seemed to be less favourable, or at least more difficult, than frontal ones. We shall see that five of the six fatalities occurred in occipital cases.

FIG. 537.—*Case* 37. Tripod incisions for parietal wound; second day. Note small swelling over forehead where penetrating wound existed: also parotid drain.

The wound in the following case was parieto-occipital, and, like the foregoing, a transverse gutter wound. It was one of the earlier cases in the series, when we were still attempting to cover defects with flaps.

Case 38.—Pte. P. P. (Serial No. 52½). **Parieto-occipital gutter fracture, brain extruding; indriven bone fragments. Homonymous hemianopsia. Operation: closure by flap. Infected fungus. Recovery.**

Admitted Aug. 16, 1917, 7.20 p.m.—Went over parapet at 5 a.m., wearing helmet; no recollection of subsequent events until being dressed at a field ambulance. Has had nausea and vomiting. Complains that his head is bursting.

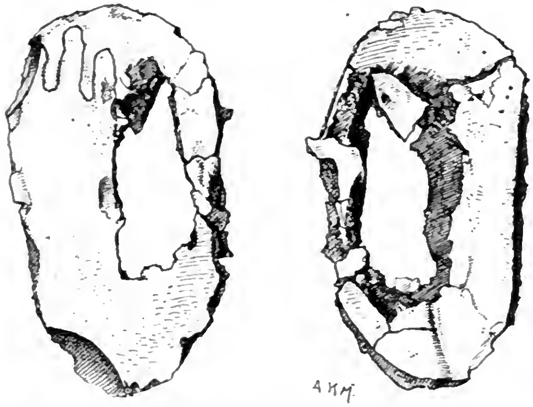
Wound.—Transverse gutter wound, 6 cm., over parieto-occipital suture, crossing mid-line, slightly more to the left. Cerebral substance extruding. *X*-ray report: "Fracture with indriven bone fragments, together with small pieces of metallic dust."

FIG. 538.—*Case* 37. Wounds before evacuation, fifth day.

Neurological Findings.—A low grade of choked disc. Unable to recognize objects, though vision not entirely lost; "things look hazy" to him. Some weakness of right arm and leg, without sensory impairment. Deep reflexes bilaterally + +, with ankle clonus. Equivocal plantar reflexes.

Aug. 17.—Resuscitation ward during night; wound meanwhile Carrelized; became dull, vomited several times, and would no longer co-operate.

Operation, 9 a.m. (28 hours).—Novocain. Excision of dirty scalp wound, with outlining of plastic flap for closure. Block trepanation encircling depressed area (*Figs.* 539, 540). On elevating bone disc momentary sharp bleeding occurred from sinus; promptly checked with lateral clips. Tear in dura, with protruding fungus. Dura incised to margins of bone opening. Thorough irrigation of pulped and hæmorrhagic cavity in left parieto-occipital lobe; removal of innumerable small fragments of bone, many of which came away in the eye of the catheter. Defect covered by sliding flap, leaving small denuded area at side with lateral drainage.



FIGS. 539, 540.—*Case* 38. Transverse gutter fracture at occipito-parietal suture; few bone fragments adherent to inner surface.

Post-operative Course.—Aug. 20.—Return of vision in left fields, leaving a sharply-cut right homonymous hemianopsia. The weakness of right arm and leg persists. Aug. 22.—Flap protruding, though incision itself appears without reaction. Wound partly opened and Carrelized. Temperature has remained practically normal. Aug. 27.—An infected fungus underlying the flap. Attempts to Carrelize unsuccessful. Lumbar puncture: 20 c.c. of clear fluid; culture negative. Sept. 20.—Wound slowly cleaning up. Flap holding. Comparatively little discharge. General condition excellent. Neurological symptoms unchanged; right homonymous hemianopsia; slight weakness of right side. Evacuated.

Subsequent Reports.—Dec. 7 (by letter).—At Gifford House Auxiliary Hospital for past month. Wound healed; is up and about: slight weakness of right side persists. Dec. 22, King George Hospital.—Vision normal. Has had a cap with plate made. Normal power of right side largely regained. Feb. 2, 1918, 3rd London General Hospital (by letter).—Has been advised to have a bone-graft operation, from rib, to fill small defect: does not like the idea, as he is "fed up" with hospitals, and feels well enough to get home.

This case furnishes a typical illustration of the risks of covering in a bone defect overlying a dural opening and damaged brain by the flap method. For in case the removal of the devitalized cerebral tissue and the showered bone fragments is incomplete, and trouble ensues therefrom, direct access to the area is precluded unless the flap is largely sacrificed. A faulty procedure of this kind was the cause of a number of fatalities in the series.

This case was one of the first in which the principle of suction was hit upon—due to the withdrawal of a few bone fragments in the eye of the catheter, which at the time was being used largely for irrigation purposes and as a means of detecting bone fragments without the advocated introduction of a finger.

The Fatal Cases.—As stated, there were 6 fatalities in this group, one of them frontal, the other five all occipital—in fact only two strictly occipital cases recovered. Cases 35 and 38, reported above, being classed as parieto-occipital.

The *frontal* case was hopeless from the outset, and it properly belongs to *Group VII*, as both ventricles were found at autopsy to have been opened, though this was not recognized at the operation.

Case 39.—Pte. W. J. (Serial No. 201).

Oct. 20, 1917.—Large median transverse gutter wound exposing both frontal lobes; destroying falx and longitudinal sinus. Complete loss of inhibition: noisy, jocular, uncontrollable. Attempted repair, with closure, after removal of indriven bone and checking of deep-seated bleeding. Secondary hæmorrhage on second day, with development of huge fungus. Death on seventh day; temperature 107°.

Autopsy.—Radiating lines of fracture; widespread encephalitis, meningitis, and ventriculitis; large infected fungus.

The five *occipital* cases follow, the last of them of sufficient interest to report at some length.

Case 40.—Rfm. J. H. (Serial No. 30).

Aug. 3, 1917.—Lying out twenty-four hours; multiple gassy wounds of head, back, and arms. Minute punctured wound of right occiput; indriven bone; stinking abscess of occipital lobe (culture: *B. perfringens*, staphylococci, coliform bacilli). Death third day.

Autopsy.—Generalized gas infection of brain and lumbar muscles.

Case 41.—Pte. A. W. (Serial No. 65).

Aug. 17, 1917.—Without history; irrational; neurological examination futile. Large circular occipital wound; brain extruding. Resuscitation ward twenty-four hours; condition improved; right homonymous hemianopsia demonstrated.

Operation.—Imperfect toilette; defect covered by flap. Broken-down wound with large fungus. Symptoms suggesting meningitis on tenth day: lumbar puncture. turbid fluid. Death Sept. 16 (thirtieth day).

Autopsy.—Radiating fissures from bone defect to vertex. No apparent meningitis; ventricles clear; large abscess in temporo-sphenoidal lobe.

Case 42.—Pte. C. W. (Serial No. 122).

Sept. 21, 1917.—Wounded previous day going over top; wearing helmet. Left homonymous hemianopsia. Vision greatly reduced on right. Multiple body and scalp wounds, including a very large dirty occipital gutter wound; brain extruding.

Trepanation *en bloc*; laceration of dura beside sinus; right lobe much pulped; usual toilette, but incomplete recovery of bone fragments. Large wound of back; also of shoulder. Gas infection of all wounds; fungus cerebri. Death third day; temperature 105°.

Autopsy.—Gas encephalitis; vessels full of bubbles; blebs under arachnoid; entire brain pasty and soft.

Case 43.—Pte. T. H. (Serial No. 128).

Sept. 21, 1917.—Semi-conscious. Foul gutter wound of left occipito-mastoid region. Neurological tests impossible. Marked nystagmus.

Fragmentary trepanation; removal of blocks of bone driven into lateral sinus and occipital lobe; partial closure. Wound infected (staphylococci and streptococci); lumbar puncture (pure streptococci). Death third day.

Autopsy.—Mastoiditis. Linear fractures radiating to foramen magnum and over petrous bone. Subdural clot over left hemisphere. Track containing a bone fragment not recovered passes through occipital lobe to left cerebellum, which is much contused. Septic meningitis.

The last of these five fatal occipital cases is as follows. As in the three foregoing ones, there was an incomplete treatment of the track, with retention of soiled bone fragments, which were later extruded with a developing fungus. The operation was complicated by bleeding from the sinus.

Case 44.—Pte. F. B. (Serial No. 101). **Occipital gutter wound. Bilateral contusion; central blindness. Sinus injury. Incomplete toilette of pulped cavity in right occipital lobe. Convulsions. Gas infection. Meningitis. Death.**

Admission, Sept. 14, 1917, 5 p.m.—Struck by a fragment of shell about noon; wearing helmet (*Fig.* 541). Knocked down, but not unconscious. Right side weak; has not attempted to walk. Some headache; moaning, weeping; pulse 120.

Wound.—A dirty 7-cm. transverse gutter wound crossing midline of occipital prominence. Case marked "Urgent; bleeding from sinus." Wound had been packed with gauze. *X*-ray report: "Fracture of bone, with indriven fragments."

Neurological Findings. — Central blindness; does not see flashlight. Deep reflexes active, equal.

Operation, 10 p.m. (*circa* 10 hours).—Novocain; cerebellar table. Wound excised; bone disc (*Figs.* 542, 543) encircled. On elevating disc and removing gauze plug, fresh bleeding started from sinus; checked by momentary pressure and hot saline. Laceration of the dura over right occipital lobe, with much pulping of lobe. Disorganized tissue thoroughly removed by suction and irrigation. Several bone fragments from depth of 5 cm. removed, together with pieces of stuffing of helmet. Given a drink on request: immediate vomiting, causing active bleeding afresh from sinus; bleeding controlled after some moments by placement of two muscle grafts. Owing to this complication, no further attempt made to remove remaining fragments. Partial closure of wound.

Post-operative Course. — Sept. 16.—Scalp wound shows infection. All sutures removed. Brownish pus with bubbles of gas. Lumbar puncture: 30 c.c. of bloody fluid under tension (Capt. Leitch: "Cerebrospinal fluid sterile; pus from brain, *B. perfringens*"). Sept. 18.—Wound looks better. Some return of vision. Recognizes light objects; also blue colours. Sept. 21.—A series of general convulsions yesterday and to-day. Fragments of

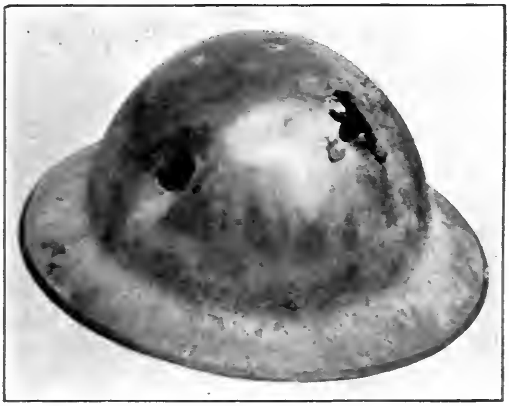
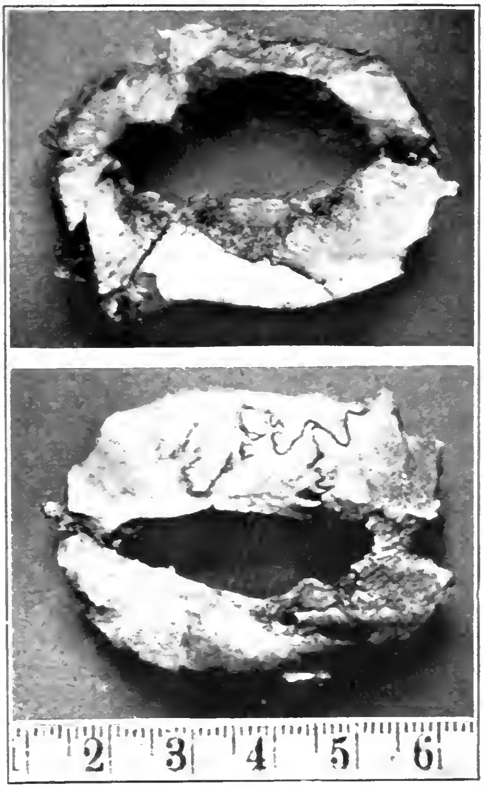


FIG. 541.—*Case* 44. Perforated helmet associated with occipital gutter wound.



FIGS. 542, 543.—*Case* 44. Showing outer and inner aspects of occipital gutter fracture: all fragments detached.

bone removed from track in herniating brain. Fungus increasing. Sept. 24.—Continued convulsions during past three days; increasing fungus. Sudden terminal rise in temperature (*Fig.* 544), doubtless from meningeal infection. Death.

Autopsy.—Three linear fractures radiate from defect; one extending up over vertex for 8 cm., another down into the posterior fossa to foramen magnum, the third over the right parietal bone. Extensive meningeal infection. Necrotic fungus protrudes from right occipital lobe; left lobe badly contused and pulped, though overlying dura intact. No septic thrombosis of sinus. Muscle grafts in place.

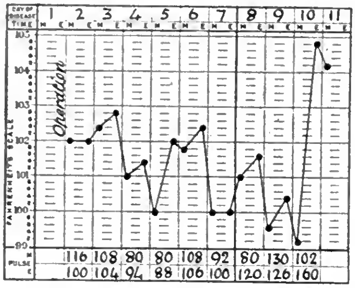


Fig. 544.—*Case* 44.—Incomplete operation, with terminal meningitis.

The fatalities, as can be seen, have been due to abscess formation, meningitis, and gas encephalitis. It is regrettable that there were no opportunities to study these brains either bacteriologically or histologically, or to preserve some of them for subsequent study.

The question of an encephalitis due to the *B. Welchii* is an important one, in view of the prevailing idea that gas infection is a muscle disease. There can be little doubt as to its existence, and the subject deserves careful investigation. It is of vital importance in these cases, as in wounds elsewhere in which a foreign body with gas bacilli attached has become lodged, that all the devitalized tissue be removed together with the projectile and bone fragments, if that is a possibility. It is the reason why so much stress has been laid on the painstaking toilette of the cerebral track, as well as of the wound of the scalp and cranium, in these cases.

Fortunately, we have the promise of an effective antitoxin against *B. Welchii* infection; but though amputations for gas infections may become as rare as tracheotomies in diphtheria, and many of these disastrous gas-bacillus infections of the brain may be controlled, we nevertheless will have to employ a no less fastidious surgical technique.

Group V.—PENETRATING WOUNDS WITH PROJECTILE AS WELL AS BONE FRAGMENTS LODGED IN BRAIN.

A still more serious form of injury is one in which a missile, even though not infective in itself, has nevertheless passed through soiled coverings, with every chance of its inoculating the brain with infective material. In the cases constituting the preceding section (*Group IV*), as we have seen, despite the widely indriven bone fragments, the direct implantation of pathogenic organisms along with these fragments need not occur. However, since the brain is exposed and extrudes in both types, there is an equal risk of surface infection—possibly, indeed, greater in *Group IV*, in view of the gutter character of many of the wounds. In the presence of a lodged projectile, on the other hand, there is greater likelihood of a primary deep-seated rather than a surface infection.

In the complete series of 219 operation cases, the largest number fall in this *Group V*, for owing to the technical difficulties of the operations, and the differences of opinion regarding the proper method of conducting them, chief

attention was paid to this particular type of injury. Some, indeed, go so far as to advocate withholding operation altogether, for unquestionably many of the smaller implanted fragments are well tolerated (cf. *Case* 37, *Fig.* 537), and such local infection as may occur may be successfully overcome without operative intervention.* Indeed, in our series of unoperated cases there were several with a penetrating projectile, all of which have done well. On the other hand, these particular cases would have done equally well with a local operation, and the risks they took would have been lessened. I have come to this opinion, not only because of the numerous examples of abscess which have developed in unoperated cases sent to the base, but also because of the many instances in this particular series in which death occurred from a small abscess at the end of a track which after ten days or two weeks broke into the ventricle.

The cerebral lesions which may occur are so multiform that I see no way of making neurological subdivisions which could be of any value for our present purposes. The tracks made by the missile vary from those a few centimetres in depth to those which completely traverse the brain without emerging; or the missile may rebound from the skull and take a new course. In one brain which was studied, the projectile ricocheted twice, making three distinct tracks in different directions before it lodged. The degree of trauma produced may be promptly fatal, or negligible, depending upon many elements —the direction of the missile, its size, whether in its course it has injured a blood-vessel of any magnitude, and so on. These matters can only be touched upon here; they deserve a separate discussion.

Disregarding all other elements which affect the prognosis in penetrating injuries of this type, and confining ourselves to the hazards of infection alone, the cases, like those of the foregoing group, may be divided into two classes; (*a*) *Those in which the ventricle has escaped injury* (41 cases; 26 recoveries; mortality 36·6 per cent); (*b*) *Those in which the projectile has lodged in the ventricle or traversed it* (16 cases; no certified recoveries). Among the recovered cases in the (*a*) class, it is quite possible that there were examples of unidentified ventricular penetration; but that the condition is a serious one is evidenced by the fact that the missile was found lodged in the ventricle, or the ventricle penetrated, in more than half of the fatalities occurring in this entire group.

For the reason given in the section dealing with *Group IV*, the cases with ventricular penetration, owing to their more grave prognosis, will be detailed in a later section (*Group VI*). However, apart from the course, direction, and depth of penetration of the projectile, the factors concerned in wounds of this type are the same, whether the ventricle be involved or not. Hence, from a broad point of view, the few facts relating to all the wounds with a projectile lodged in the brain will be considered together.

There were 57 cases all told, with 31 deaths: a mortality of 54·3 per cent.

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* This is comparable to saying, as was said earlier in the war, that penetrating wounds of the abdomen sometimes recover spontaneously, therefore withhold operation in all cases. It was with great difficulty that this idea was supplanted by the view that far more cases would recover after a properly conducted operation than if left to their own salvation.

Site of Entrance.—The external wounds were cerebellar (i.e., suboccipital) in 6 cases, with 1 death (mortality 16·6 per cent); temporal in 18, with 6 deaths, all of the ventricular type (mortality 33·3 per cent); frontal in 11 cases, with 6 deaths, one ventricular (mortality 54·5 per cent); occipital in 7 cases, with 5 deaths, one of them ventricular (mortality 71·4 per cent); parietal, including wounds of the vertex, in 14 cases, with 12 deaths, six of them ventricular (mortality 85·7 per cent).

In *Group IV*, as may be recalled, there was a great predominance of parietal wounds (22 cases) over temporal ones (1 case), whereas these figures for *Group V* show a corresponding predominance of temporal wounds. Moreover, the prognosis of the temporal wounds would seem to be infinitely better, for 12 of the 26 recoveries in the series were in temporal cases—indeed all of the temporal cases, excluding the six with ventricular penetration, recovered; whereas, in contrast, out of 10 parietal cases, only 2 recovered.

The penetrating temporal and cerebellar cases, in short, appear to have a far better prognosis than do those with penetrations of the vault. It is difficult to account for this, unless one may assume that a projectile with sufficient velocity to penetrate helmet as well as skull would kill in the unprotected temporal or suboccipital regions, and that the penetrations with small projectiles so commonly seen in these regions would not occur if the parts were protected by the helmet.

Type of Wound.—With but few exceptions, all have been of the direct penetrating variety, with relatively small scalp wounds. Despite the tendency to radiating meridional fissures, the extent of which depends largely upon the size of the projectile, the physical peculiarities of the individual skull, and the anatomical seat of impact, the cranial injury, like the scalp wound, is less difficult to deal with than the large gutter wounds characterizing the preceding *Group IV*. By the external appearances alone, therefore, one may be easily misled into giving a favourable prognosis in these cases in the early hours or days after the injury.

Relation to the Helmet.—In the 21 cases from which a history could be obtained, the helmet, according to the patients' statements, was being worn in all but one instance; in one or two others it had been blown off by a shell explosion, whether before or at the moment of receiving the wound is not clear. A definite history of penetration was given in six cases, and in a few others penetration was certified by finding bits of helmet; but what is more important, in 29 the projectile was either known or, from the situation of the wound, may be supposed to have passed under the helmet.

It has been found on careful examination of the shell fragments removed at operation or autopsy, that many of them exhibit rubbed or burnished sides, edges, or angles, a condition which in all probability was produced by the passage through the helmet. This is the more likely, since the projectiles from patients not wearing their helmets, and those known to have passed underneath, do not show these smoothed surfaces. This has made it possible to correct the hearsay records of the *questionnaire*, and to state with some assurance that in 25 of the 57 cases the missile had penetrated the helmet.

Condition on Admission.—A large number of the patients (35 out of the 57) were in such a condition that no history could be elicited, and of these

35 cases 29 died. From this it would appear that only six patients, about 1 in 6, who were admitted in an unconscious or a stuporous state, with a projectile lodged in the brain, recovered after operative intervention. On the other hand, only one of the patients (*Case* 1) out of the 21 who were sufficiently conscious to give some account of themselves on admission, succumbed.

There was more than one cranial injury in 5 of the recovered cases, and in 9 of the fatal cases. There were complicating wounds elsewhere of a comparatively mild character in 2 cases, and of a severe character in 7 cases. These multiple wounds were unquestionably responsible for the fatalities in at least four instances.

The Projectile.—The missile, so far as ascertained in the 57 cases, and certified by operation or autopsy, was a shell or bomb fragment in 48, a shrapnel ball in 2, the casing of a rifle ball in 1, the fragment of a helmet in 1. The lodged fragments were single in 41 cases, multiple in 15.

The missile was removed in 22 cases, 12 of them with the magnet and nail in the manner elsewhere described. In 35 cases it was not removed: either no effort was made to extract it, owing to its small size or inaccessibility (21 cases); or the effort was abandoned, as persistence in this direction was regarded as more likely to endanger the ultimate prognosis than leaving the fragment in position.

The mortality in the 35 cases with retained missile (13 ventricular) was 60 per cent; in the 22 cases with extracted missile (4 ventricular) it was 31·8 per cent. There are of course many obvious factors affecting these results. For example, the irremovable fragments are apt to lie deeper and to have caused more damage; on the other hand, they are often very small, and well tolerated. Infection, however, plays the chief rôle in the mortality of the cases which have survived to reach the casualty clearing station. Comparatively few of the penetrating cases died early from the compression effects of the cerebral injury before the period of superimposed infection.

The size of the projectile is an important element. The largest fragment, which penetrated the helmet and lodged, weighed 46 grm., the smallest less than ½ grm. The smaller fragments, naturally, are far more commonly seen.

One can usually tell, by comparing the missile and the cranial defect in the trepanation blocks, in just what position the projectile entered the skull; and what is perhaps less well known, one can tell by the burnished or rubbed surface of the fragment in just what position it passed through the helmet. As we shall see, some of the examples of multiple projectiles (e.g., *Case* 52, *Fig.* 559) are accounted for by the shell fragment having been split on its passage through the tough helmet.

It is regrettable that cultures were not taken in all instances, but circumstances hardly permitted of this. The impression is abroad that the foreign bodies are commonly found sterile. The several projectiles of which cultures were made by Dr. Leitch after operative removal all showed organisms of greater or less pathogenicity. It is a matter which deserves further study.

A few selected histories will illustrate some of these points. The *temporal* cases, being the most numerous, may receive first consideration. The following is an example of a trifling wound of penetration of the type which doubtless

may often recover by itself, as in *Case* 37 cited in the preceding group. The man had multiple wounds, all under the level of the helmet—one of the eyebrow, which was supposed to be the wound of entrance for the small intracranial fragment disclosed by the *x* rays. Not until the blood-encrusted scalp was shaved was the wound in the temporal region disclosed.

Case 45.—L.-Cpl. G. B. (Serial No. 43). **Multiple wounds. Minute shell fragment penetrating from right temporal region to the opposite hemisphere. Magnet extraction. Recovery.**

Admission, Aug. 11, 1917, 3.45 p.m.—Wounded while wearing helmet on morning of Aug. 10 ; unconscious ; lying out for twenty-four hours ; made his own way back to dressing station this morning. In good general condition ; headache ; apathy ; no vomiting.

Wounds.—Multiple, of head (*Fig.* 545) : (1) Severe wound of right brow of gutter type, no brain extruding ; (2) Transverse tear of lower lip and chin, with loss of substance ; (3) Penetrating wound over angle of jaw, with fracture ; (4) Minute puncture in right temporal—not disclosed until head shaved. *X*-ray report : "Small intracranial projectile in left hemisphere."

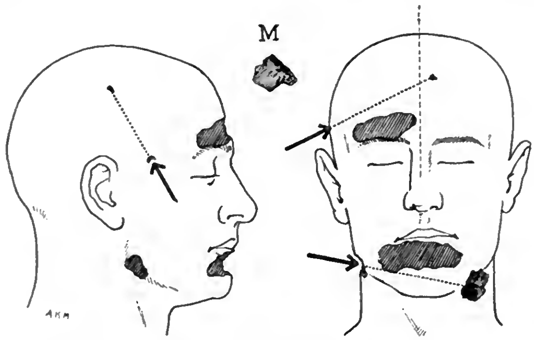


Fig. 545.—*Case* 45. Diagram to show situation of wounds: cranial penetration below helmet by 0·12-grm. missile (M) (natural size).

Operation, 5 p.m. (*circa* 36 hours).—Ether. Supposed wound of entrance over brow found to be a scalp wound ; excised ; closed. On pressing temporal muscle, brain substance extruded from small punctured wound ; flap reflected, disclosing penetrating wound and bleeding meningeal vessel ; trepanation ; dura found punctured, with bleeding artery at margin ; catheter enters track 10 cm ; nail inserted ; magnet extraction of minute 0·12-grm. missile (*Fig.* 545M) ; partial closure, with gutta-percha drain. Wound in jaw passes across throat, where large 12·5-grm. projectile, portion of detonator, was found lodged behind opposite angle of jaw. Lip wound loosely closed over Morison's paste.

Subsequent Notes.—Temperature normal. No untoward symptoms ; perfect healing of cranial wound ; others in good condition. Evacuated tenth day. No later report.

The disclosure in this case of injured meningeal and cortical vessels shows how important it may be to investigate the underlying conditions in wounds over the Sylvian area, even when the wound of penetration may seem trifling, Favourable as they have proved to be, one cannot belittle these temporal operations, however, for they are often very troublesome, owing to bleeding, which may be started afresh by the trepanation.

It is in the temporal region that one may with advantage employ flap operations, for, owing to the thickness of the muscle, proper exposure without excessive damage to the fibres may otherwise be difficult to secure. On replacing the flap, a single wick of gutta-percha tissue passed through the wound of entrance is usually all that is necessary, and excision of the scalp wound has rarely been practised.

Case 46.—Pte. J. D. (Serial No. 148). **Penetrating left temporal wound, with lodgement of two metal fragments. Direct drainage.**

Admission, Sept. 27, 1917, 4 a.m.—No history obtainable; semi-conscious: pulse 60.

Wound.—Small, penetrating, left temporal (cf. *Fig.* 546). *X* rays show metal fragment 5 cm. in temporal lobe.

Neurological Findings.—When roused, proved completely disoriented; apparent aphasia. Possible slight weakness of right face. Deep reflexes active, without clonus.

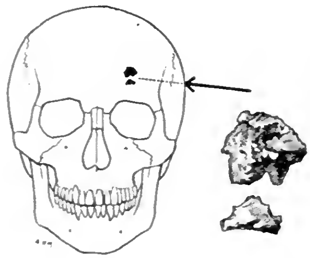


FIG. 546.—*Case* 46. Showing 1·2-grm. shell fragments (natural size), and course under helmet.

Operation, 7 p.m. (over 15 hours).—Novocain. Temporal flap reflected: penetrating wound of squamous wing enlarged, disclosing ragged tear in dura about 1 by 2 cm.; immediately a large clot with disorganized brain substance and two small unrubbed bits of shell extruded themselves (*Fig.* 546). Cavity irrigated and sucked: dichloramine-T: cigarette drain of gutta-percha through unexcised wound of entrance. Closure of flap.

Post-operative Note.—Perfect healing: sutures removed third day (*Fig.* 547): rapid return of speech: evacuated fifth day with normal temperature.

Subsequent Reports.—Oct. 18, No. 47 General Hospital.—Speech and mental condition improved; evacuated to U.K. Jan. 18, 1918 (by letter).—" From King George Hospital to Convalescent Auxiliary Hospital, where he is at present, practically free from all symptoms." Feb. 1.—Reports quite well: some headache in stooping.

FIG. 547.—*Case* 46. Temporal flap, third day, before removal of sutures; drain in wound of entrance.

The following case shows that at times the more simple straight incision in the line of muscle fibres, as for a decompression, may be preferred to the flap exposure, if the point of penetration happens to be sufficiently near the usual line of incision for this operation. The missile in this case was somewhat larger and the damage greater than in the foregoing.

Case 47.—Pte. H. R. (Serial No. 186). **Right temporal penetration by small shell fragment. Decompression incision. Magnet extraction. Cultures made. Recovery.**

Admission, Oct. 13, 1917, 5.20 a.m.—In good condition. Wounded 6 p.m. evening before; wearing helmet. No loss of consciousness; walked a short distance; headache and vomiting; numbness of left arm.

Wound.—Penetrating variety, right temporal. *X*-ray report: "Foreign body in right temporal lobe."

Neurological Findings.—Slight left facial weakness; moderate nystagmus; otherwise no positive signs.

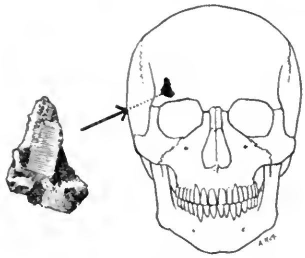


FIG. 548.—*Case* 47. Showing 2-grm. shell fragment (natural size), and course under helmet.

Operation, 12 noon (18 hours).—Novocain. Incision as for subtemporal decompression (cf. *Fig.* 549), disclosing perforation of the bone low in temporal fossa. Primary burr opening, with enlargement of defect. Much disorganized brain with clots irrigated and sucked from track, which was 5 cm. in depth. Missile (*Fig.* 548) removed by magnet on first trial. (Cultures: *B. proteus* only.) Wound closed, with direct drain.

Post-operative Course.—Uneventful; perfect wound healing (*Fig.* 549); highest temperature 99°. Evacuated ninth day.

Subsequent Reports.—Oct. 22, No. 14 General Hospital.—Condition normal; no headache. Evacuated to England. Feb. 13, 1918 (by letter).—Was kept in bed for two months owing to dizziness; drum of right ear found perforated; gets headaches if too active; in S.A. Military Hospital, Richmond.

A slightly more severe type is the following, with a wound sufficiently high and of such size as to favour a tripod incision with block trepanation. The penetration was deep enough and the damage severe enough to injure the geniculo-calcarine pathway. The square missile had punched its way through the squamous wing and carried the bone fragment with it.

FIG. 549.—*Case* 47. Subtemporal incision, third day; wound of entrance opposite pinna.

Case 48.—Pte. J. W. (Serial No. 165). **Penetrating right parieto-temporal wound: shell fragment. Contralateral palsies; homonymous hemianopsia; epilepsy. Recovery.**

Admission, Oct. 3, 1917, 5 a.m.—Wounded previous evening; shell explosion; missile went under helmet; temporary unconsciousness; tried to walk, and found left side weak.

General Condition.—Fair; pulse 68; headache.

Wound (*Fig.* 550).—Penetrating variety, 3 cm. above right pinna; brain extruding. *X*-ray report: "Fracture of squamous bone; large missile 5 cm. deep."

Neurological Findings.—Weakness of left face and arm: tongue to left; left

homonymous hemianopsia: Deep reflexes: left active, with positive Babinski: right barely elicited.

Operation, 2 p.m. (*circa* 18 hours).—Novocain. Tripod incisions: reflection of flaps, exposing fungus with bleeding vessels requiring clips, and a square punched-out window in the squamous wing. Trepanation *en bloc* (*Fig.* 551). The bone fragment corresponding with the defect lay at 3 cm. depth, and the missile beyond at 6 cm., resting on the tentorium. Attempt at magnet extraction unsuccessful; removal with duck-bill forceps of a 5-grm. piece of copper driving-band of a 4·2 shell. Toilette of cavity, with irrigation and suction: dichloramine-T: closure without drainage.

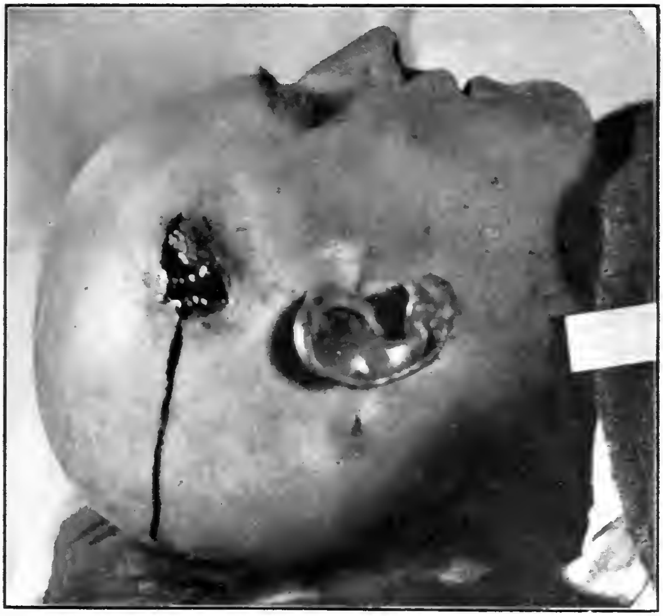


Fig. 550. *Case 48.* Wound of entrance.

Post-operative Course.—Temperature practically normal throughout: perfect wound healing: sutures removed third day (*Fig.* 552): early clearing up of upper quadrants of hemianopic fields: three left-sided focal seizures, beginning in hand, on the sixth day: improvement in left-sided weakness: evacuated on eleventh day.

Subsequent Reports.—Oct. 22, No. 18 General Hospital.—In good condition: no alteration in symptoms: evacuated to England. Dec. 14 (by letter).—Discharged from army. "Free from all symptoms—quite well."

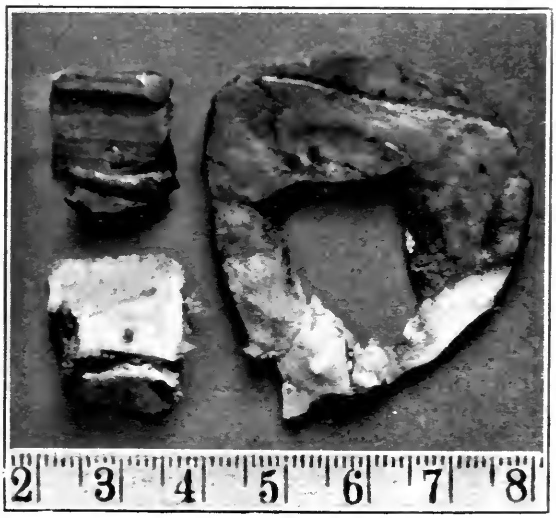


Fig. 551.—*Case* 48. Showing temporal block with 5-grm. copper missile and punched-out bone fragment (natural size).

The other seven temporal cases, all of which recovered, range from those of the above type to those with fragments driven through to the other hemisphere or to the occipital lobe. The foreign bodies range up to 6 grm. in weight

—none of them very large therefore—none showing evidence of passage through a helmet. In three the foreign body was retained, The four fatalities. as stated, all occurred in ventricular cases (cf. *Group VI*).

FIG. 552.—*Case* 48. Wound on third day.

The *cerebellar* penetrations, though few in number, were as favourable as the temporal ones, the single fatality out of the 6 cases being due to a gas encephalitis. Like the temporal cases, moreover, these are suited to a flap operation.

The history of the five that survived is very similar; two of them may be given in illustration.

Case 49.—Pte. T. T. (Serial No. 172). **Penetrating suboccipital wound. Hemilateral flap exposure of cerebellum; magnet extraction of missile; direct drain.**

Admission, Oct. 4, 1917, 10 p.m.—Wounded at 10 a.m., shell fragment passing under helmet; temporary unconsciousness; aroused, and walked back with assistance; very unsteady, " as though drunk "; right leg worse than left; very dizzy; frequent vomiting. General condition good.

Wound.—Penetrating type; right sub-occipital (cf. *Fig.* 554). *X*-ray report: " Missile 4 cm. deep below mastoid process."

Neurological Findings.—Characteristic right cerebellar symptoms; vertical and lateral nystagmus, coarser to right; inco-ordination, particularly of right side, affecting both arms and legs, shown by usual tests. Deep reflexes exaggerated, without clonus; dorsal toe-response on left. Deafness in right ear.

Operation, Oct. 5, 10 a.m. (24 hours).—Novocain; cerebellar position. Unilateral exposure by flap, disclosing sub-occipital penetration without radiating fractures; removal of bone from sub-occipital area; bone fragments, clots, disorganized cerebellum extruded from dural opening. Missile detected by catheter at depth of 5 cm.; futile attempt to catch missile in forceps; magnet extraction, on first attempt, of 1·8-grm. unrubbed shell fragment (*Fig.* 553). (Cultures gave abundant growth of an unidentified bacillus, with cocci.) Dichloramine-T. Closure of flap; direct drain through track with gutta-percha wick.

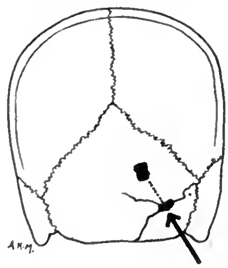


FIG. 553.—*Case* 49. Showing 1·8-grm. fragment (natural size), and course under helmet.

Post-operative Course.—Uneventful recovery: highest temperature 100°; sutures and drain removed third day (*Fig.* 554); healing by primary union; cerebellar symptoms much lessened. Evacuated tenth day.

Subsequent Reports.—Oct. 22, No. 11 General Hospital.—Some nystagmus, ataxia, and headache persist; also right deafness. Good condition; wounds solidly healed. Evacuated to England.

The following case was very similar, cultures of the fragment showing *B. Welchii.*

Fig. 554.—*Case* 49. Flap incisions on third day, with wound of entrance.

Case 50.—Pte. E. W. (Serial No. 189). **Penetrating shell fragment in right cerebellum. Magnet extraction. Recovery.**

Admission, Oct. 13, 1917, 2 p.m.—Was wounded 1 p.m. previous day; sitting down; wearing helmet; blown into air; unconscious; recovered, and crawled back to trench as too unsteady to walk; very dizzy; nausea but no vomiting. Good general condition.

Wound.—Small penetrating type, right sub-occipital. X-ray report: "Indriven bone and metal fragment."

Neurological Findings.—Coarse nystagmus, more marked to left. Some static ataxia; very little inco-ordination of arms. Deep reflexes exaggerated, equal; no clonus; normal plantar responses.

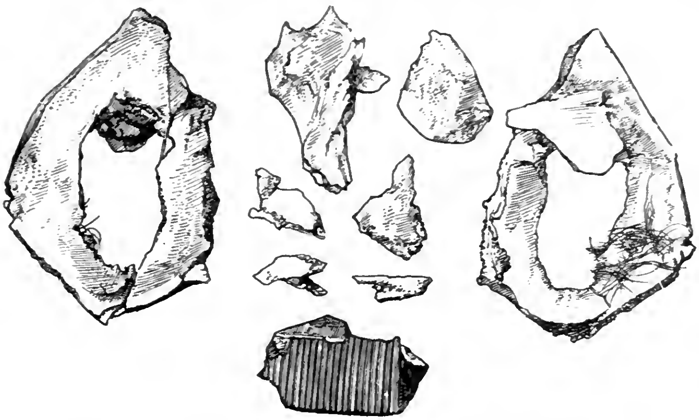


Fig. 555.—*Case* 50. Showing trepanation block, inner surface covered with hair; bone fragments and 6·3-grm. missile (natural size).

Operation, 5 p.m. (28 hours).—Novocain; cerebellar table. Incisions for unilateral cerebellar flap procedure; exposure of penetration in bone and very dirty fungus, with masses of hair. Trepanation *en bloc* (*Fig.* 555) to edge of mastoid. Dural penetration just below lateral sinus, which was uninjured. Cerebellar hemisphere much disorganized; many indriven fragments of bone. Missile not detected

by catheter; extraction from bottom of cavity at 5 cm. depth, on first attempt with magnet, of a 6·3-grm. unburnished shell fragment, together with six additional pieces of indriven bone. Usual toilette of cavity; dichloramine-T. Closure of flap, with direct drain of gutta-percha introduced through unexcised wound of entrance. (Cultures of missile gave mixed organisms, *B. Welchii* predominating.)

Fig. 556.—*Case* 50. Operative incision on third day, with wound of entrance.

Post-operative Course.—Uninterrupted convalescence; sutures removed third day (*Fig.* 556); perfect wound healing; highest temperature 99°; lumbar puncture fourth day owing to headache (culture sterile); lessening of neurological symptoms; evacuation eighth day.

Subsequent Reports.—Dec. 18, Suffolk Auxiliary Hospital.—Perfect recovery; discharged to command depôt. Dec. 23 (by letter from home).—Only complaint numbness of scalp owing to division of sub-occipital nerves. Feb. 20, 1918.—On duty at command depôt; in good health; some discomfort on stooping.

The single fatality among these simple cerebellar penetrations was due to a gas infection, and the outcome in the case just recorded may be regarded as fortunate, in view of the cultural findings in a wound twenty-four hours old. Of the three other cerebellar recoveries, in one the missile (5-grm. shell fragment) was removed as above; the other two had small fragments which were not extracted—one of them, a case operated upon by Captain Horrax, in which the fourth ventricle was apparently opened.

As has already been stated, the fact that the prognosis in penetrating wounds from missiles passing under the helmet is better than from those which pass through it, should not be misread as an argument against the helmet. Had the helmet sufficiently protected temporal and occipital regions, doubtless many of these penetrations would not have occurred, and wounds in these situations from missiles having a sufficient velocity to have penetrated a covering helmet would probably have caused immediate death from basilar extravasations. Conversely, the penetrations traversing the helmet, which we are now to consider, would in all likelihood have been fatal had it not been worn. The results, as we shall see, were far less good.

In the 7 *occipital* penetrations, there were only 2 recoveries. In the following example the missile, a deep-lying shrapnel ball, was not recovered.

Under the impression that it must be of lead, the magnet was not employed. As the *x* rays showed it to be undeformed, it was probably of iron, as in the case reported in *Group III.* Up to this time, however, it has been well tolerated.

Case 51.—Pte. L. W. (Serial No. 171). **Left occipital shrapnel penetration, with contralateral symptoms, including hemianopsia; missile retained. Recovery.**

Admission, Oct. 4, 1917, 5 p.m.—Wounded in early morning; unconscious: on recovery walked short distance despite weakness of right side. General condition good.

Wound.—Penetrating, mid-occipital, 3 cm. above protuberance; brain extruding. *X*-ray report: "Fracture with indriven bone and shrapnel ball near midline, about at top of tentorium" (*Fig.* 557).

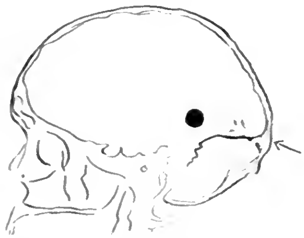


Fig. 557.—*Case* 51. Sketch from *x*-ray picture: penetrating shrapnel ball.

Neurological Findings.—Right homonymous hemianopsia, and some obscuration over left fields as well. Weakness of right arm, leg, and face, with hypæsthesia. Deep reflexes over-active; no clonus; normal plantar responses.

Operation, Oct. 5, 10 a.m. (*circa* 28 hours).—Novocain. Tripod incision encircling wound; trepanation *en bloc*; dura penetrated just to left of sinus, which was uninjured; track 8 cm. deep in left occipital lobe, sucked clean; many indriven bone fragments removed. Ball palpated with catheter; unsuccessful attempt to extract by forceps, by gravity, by change of position, and by suction through fragment of stomach-tube introduced through track; magnet not tried. Dichloramine-T. Closure with no drain.

Fig. 558.—*Case* 51. Tripod incisions; sixth day.

Post-operative Course.—Temperature averaging 99° to 100°; sutures removed third day; right hemianopsia persisting, though other right-sided symptoms subsided. Perfect healing sixth day (*Fig.* 558). Evacuated tenth day.

Subsequent Reports.—Dec. 18, 4th London General Hospital.—Perfect recovery aside from right hemianopsia, complete for left eye, upper quadrant alone for right eye. Boarded out. Jan. 14, 1918 (by letter).—In best of health; but little trouble from hemianopsia; no headaches. Discharged from army Jan. 7.

A shrapnel ball is far less likely to carry in and implant infective material than is a jagged shell fragment. Prolonged, though ineffectual, efforts were nevertheless made to extract the missile, owing to an experience with an

officer who was seen in consultation six months after he had received a similar injury resulting in hemianopsia. No effort at extraction had been made at his original operation, and there seemed to be no reason for intervention when he was seen; but six months later, following an epileptiform attack, he was operated upon by another surgeon, who found and opened an abscess cavity from which the ball was removed.

Generally speaking, missiles which are of this size and weight (an iron shrapnel ball weighs 11·7 grm.) are too large to be left *in situ* without at least an effort at removal—always with the proviso that this effort must not produce further damage.

There were only 2 recoveries in the 16 *parietal* cases, one of them a simple case with a minute missile in the opposite hemisphere, which was left without effort at extraction. The other was an injury of more serious grade. This case, the first of the series, and subjected to a most imperfect operation, nevertheless, after many periods of discouragement, finally made a complete recovery.

Case 52.—Pte. R. MacL. (Serial No. 1). **Penetrating wound of right post parietal region. Massive fracture of skull. Cerebral herniation; multiple foreign bodies, one of which caused an abscess. Ultimate recovery, with hemianopsia.**

Admission, July 23, 1917.—No history obtainable (missile had penetrated helmet).

Condition.—Restless; stuporous, but can be roused; pulse 60, later rising to 120.

Wounds.—(1) Small, penetrating type, in left temporal region; (2) Large dirty lacerated wound to right of mid-line over lambda, with extensive escape of disorganized brain matter and widespread radiating fissures, so that crepitus could be felt almost anywhere over left side of head. Marked dilatation of extracranial vessels; extravasation of blood and cerebrospinal fluid under scalp over entire head. *X*-ray report (*Fig.* 559): "Two metal fragments, right side of head, temporal region. Penetration of occiput, with extensive fractures; indriven bone."

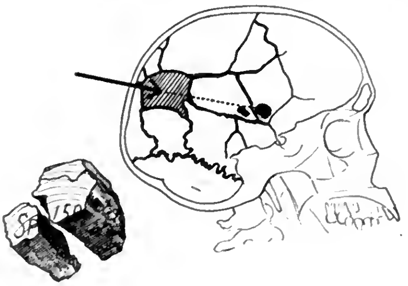


FIG. 559.—*Case* 52. Drawing of shell fragments, split in two (natural size); also position of lodgement in brain, taken from *x*-ray picture, with lines of fracture.

Neurological Findings. — Fundi show vitreous hæmorrhages obscuring disc on left; papillœdema on right; apparently complete loss of central vision. Apparent weakness of left arm. Deep reflexes hyperactive, without clonus. Normal plantar, absent cremasteric and abdominal reflexes. Possible uncinate lesion: when roused, complains of vile taste and smell.

Operation (hours not recorded).—Ether. (1) Left temporal wound excised; a few pieces of indriven bone puncturing dura removed; (2) Parieto-occipital wound excised; no treatment of track in greatly disorganized brain beyond removal of a few superficial fragments of bone; missile not recovered. Incomplete closure; drainage.

A stormy convalescence: infected wound; cerebral hernia; attempted Carrelization of wound; symptoms of abscess, presumably around retained missiles, which stereo *x*-ray plates show in temporal lobe.

Second Operation, July 30.—Ether. Vertical incision for subtemporal decompression; trepanation and opening of dura; large abscess located deep in lobe (cultures: diplococci and coliform bacilli); magnet extraction of two fragments (*Fig.* 559) from nose of shell—evidently one 7·2-grm. fragment split in two by

passage through helmet, as one surface is highly smoothed and burnished (cf. *Fig.* 562).

At the time, some fragments of bone were removed from the fungus in the posterior wound (cultures: diplococci and *B. Welchii* in abundance). Attempts to Carrelize wounds were persisted in; sudden rise in temperature on Aug. 3 (12th day) to 105°, with nystagmus, profuse sweating, involuntaries, vomiting, and collapse, which followed an irrigation in the ward; other upsets of the same kind occurred on the 19th and 31st days (*Fig.* 560).

To shorten the story: the temporal abscess healed perfectly, but the trouble from the incompletely treated track kept up for weeks, with occasional discharge

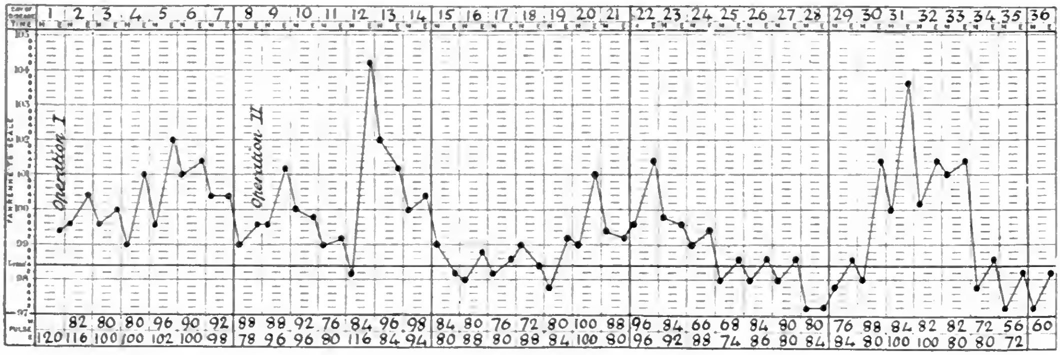
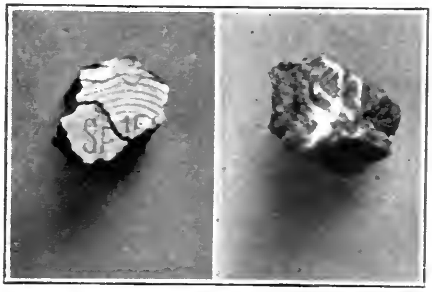


FIG. 560.—*Case* 52. Portion of temperature chart.

of fragments of bone. By September dichloramine-T was used in the wound, and gradually complete healing took place. Sept. 30 (70th day).—Evacuated in excellent condition; wounds healed; persisting left homonymous hemianopsia.

Subsequent Reports.—Many, from attending officers and patient.—Boarded out from Northampton War Hosp., Dec. 17. Discharged from army three weeks later. The hemianopsia has been partly recovered from and the fields have widened, though vision to the left remains imperfect: barring this, he regards himself as a normal healthy man; has received his discharge and returned to his occupation: no headaches whatever.

It has been difficult to do justice to the complicated story of this unexpected recovery after a sadly imperfect original operation for a serious lesion. A stormy post-operative period of this sort was, alas, too common among the cases treated in the early weeks of the service, though usually with a less happy outcome. There were many points of unusual interest which space forbids touching upon. Attention may be drawn to the abscess which formed around the retained missile, and to the split missile itself, which showed by its rubbed surface that it had penetrated the man's helmet (*Figs.* 561, 562).



FIGS. 561, 562.—*Case* 52. Two fragments put together, showing: *Left.*—Unrubbed surface: *Right.*—Surface burnished by helmet penetration.

Out of 12 cases with *frontal* penetration, 7 died, four of them in the group

with ventricular involvement. There is nothing particularly noteworthy about the 5 cases that recovered. All but one were examples of a small fragment or fragments deeply penetrating and not extracted: (1st) orbit to mid-brain; (2nd) multiple small scattered fragments; (3rd and 4th) crossing through falx and lying deep in the opposite hemisphere; (5th) traversing to occipital lobe. The operation in each was restricted to a small trepanation *en bloc*, with removal of bone fragments, toilette of the track, and closure of the wound. Frontal cases, as we shall see, of an entirely different order from these, are common among the fatal cases in this and also in a later section (*Group VIII*).

The Fatal Cases.—The single fatality in the 6 *cerebellar* cases occurred as follows.

Case 53.—Rfm. J. V. (Serial No. 47).

Aug. 12, 1917.—Semi-conscious; severe multiple wounds of arm and thigh. Penetration of skull behind left mastoid, under helmet; brain extruding. *X* rays show large foreign body about at vermis of cerebellum. Ataxia and nystagmus.

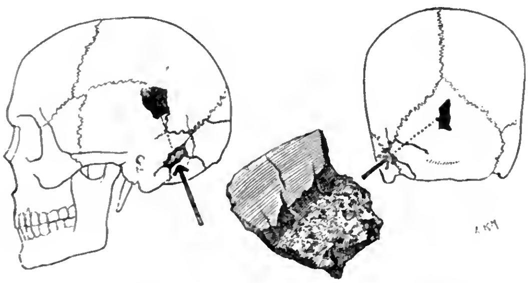


FIG. 563.—*Case* 53. Missile, 7-grm. (natural size), situation according to *x*-ray plates.

Usual cerebellar exposure (cf. *Fig.* 556). Catheter enters track to depth of 4 in. Magnet extraction of foul-smelling 7-grm. missile (*Fig.* 563), on first trial. Imperfect toilette of track. Closure, with gutta-percha drain through track. Patient restless, requiring morphia. Death, 24 hours.

Extensive gas infection, spreading through entire brain, with evidences of widespread cerebellar contusion.

A shell fragment of this size demands removal, and is almost certain to implant infective material. The case was operated upon before we came to adopt a satisfactory method for track cleansing.

The 4 fatal *temporal* cases all fall in the ventricular group, and will be described in the following section.

Brief notes of the 4 fatalities from *occipital* wounds follow, all of them, like *Case* 53, associated with sepsis arising from a soiled and incompletely cleaned track. The first was a case early in the series, with an inadequate toilette of the disorganized brain, and with the common sequel—an abscess about the foreign body, minute though it was.

Case 54.—L.-Cpl. C. L. (Serial No. 20).

Aug. 2, 1917.—Multiple wounds of scalp and extremities; penetrating wound of left occiput, brain extruding. Pulse 130. No *x*-ray examination. Aphasia.

Operation (*circa* 12 hours).—Excision of scalp wound and bone area; closure, with small drain.

Aug. 4.—Wounds infected. Carrel-Dakin treatment. Aug. 5.—Meningitis, and death the following day.

Autopsy.—Leptomeningitis. Gas abscess in occipital lobe, with infected track

leading to opposite cuneus, where lay a minute 0·1-grm. projectile of undetermined nature (? helmet) (*Fig.* 564).

Another fairly early and imperfectly treated occipital case, resulting in a spreading encephalitis, follows.

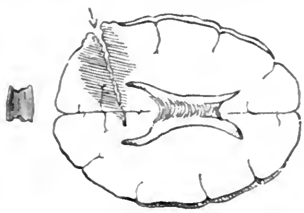


FIG. 564. *Case* 54. Showing 0·1-grm. fragment (natural size), and its track.

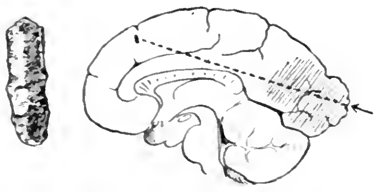


FIG. 565. *Case* 55. Showing 3-grm. fragment (natural size), and its path.

Case 55.—Rfm. J. W. (Serial No. 51).

Aug. 14, 1917.—Case lying out 48 hours. Penetrating wound of mid-occipital region; brain extruding. *X*-ray report: "Extensive linear fractures of occiput: projectile near mid-line of parieto-frontal region. Complete central blindness."

Operation.—Novocain. Closure by flap plastic, after excision of fungus and partial cleansing by irrigation of disorganized right occipital lobe.

Aug. 19.—Apparently doing well. No especial elevation of temperature. Vision to right has returned. Wound bulging slightly: opened, with escape of stinking cerebral substance, gas bubbles, and bone fragments. Carrel-Dakin treatment. Aug. 20.—An enormous fungus, largely blood-clot with bleeding surface, has developed. Aug. 24.—Death.

Autopsy.—Entire right occipital lobe a disintegrating mass of softened brain, almost abscess-like in its consistency. The track traverses the hemisphere, and the missile, a 3-grm. shell fragment with rubbed surface (*Fig.* 565), is found near the falx in the frontal lobe.

In the next fatality, death was likewise due to infection from a track in which soiled bone fragments remained.

Case 56.—Pte. E. G. B. (Serial No. 196).

Oct. 20, 1917.—H. E. shell-fragment, penetrating helmet: entered right occiput. Brain extruding. Left homonymous hemianopsia.

Operation (12 hours).—Novocain. Gutter wound, occipito-parietal suture (*Figs.* 566–568), with two tracks: one inward toward the falx, with many fragments of bone, at 5 cm. depth: four fragments removed (cultures: streptococci). Another track directly forward for 7 cm., and 4-grm. projectile (*Fig.* 567) removed from depth by magnet (culture: *B. perfringens*). Dichloramine-T. Closure without drain.

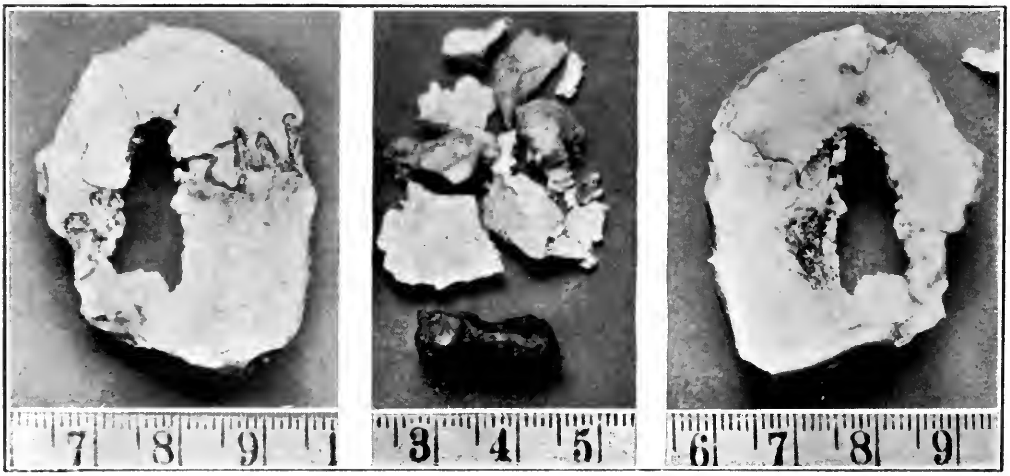
Oct. 21.—Wound re-opened: acute cerebritis. Track suction, with recovery of additional bone fragments (streptococci on culture). Drainage. Fungus cerebri. Death, 7th day.

Autopsy.—Streptococcus meningitis: sinus thrombosis: ventriculitis. Track of missile communicates with infected ventricle—probably recent communication.

The last of these four fatal cases appeared to be on the road to recovery, after a mild local infection, when an acute tetanus ended the story. In addition to his occipital penetration, there was a cervical wound which had severed his sternomastoid muscle with the spinal accessory nerve and lower branch of the facial.

Case 57.—Pte. A. F. (Serial No. 194).

Sept. 19, 1917.—Multiple wounds of neck, arm, and leg, with penetrating wound of left occiput. Unconscious ; no demonstrable local symptoms ; two foreign bodies, one supposed to be shrapnel ball.



Figs. 566, 567, 568.—*Case* 56. Showing outer and inner aspect of bone disc at occipito-parietal suture, with rubbed 4-grm. missile and bone fragments (natural size).

Operation (after 17 hours).—Novocain. Sargent's flap procedure. Entry under helmet (?) of heavy 18-grm. missile (*Fig.* 569) just above lateral sinus ; the F.B. found lying high on tentorium, and extracted ; usual wound toilette, with closure of opening in galea and lateral drains.

Sept. 21.—Wound infected, necessitating re-opening on second day (*B. perfringens*). Suction treatment ; dichloramine-T. Temperature 104°. Lumbar puncture :

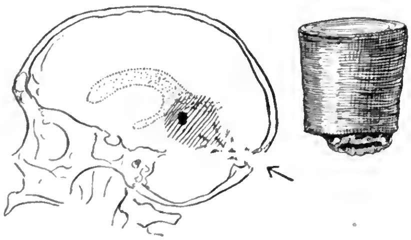


Fig. 569.—*Case* 57. Showing projectile (natural size), and course.

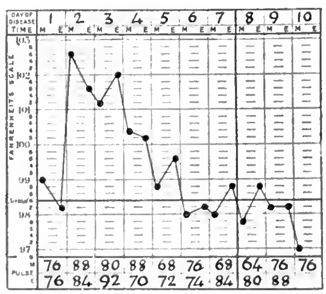


Fig. 570. Temperature chart of *Case* 57.

fluid normal ; no growth on cultures. Sept. 25.—Temperature normal ; wound cleaning rapidly. Sept. 29.—Temperature continues normal (*Fig.* 570), but there is some stiffness of jaws, increasing rapidly during day, despite intrathecal antitoxic serum ; trismus ; opisthotonos ; tetanic convulsions. Death from respiratory paralysis in 12 hours.

Autopsy.—Track of missile found communicating with posterior horn of left ventricle, which was full of thick pus.

Judging from his satisfactory general condition and normal temperature (cf. *Fig.* 570), this patient was thought to be out of danger as regards his wound infection, so that the post-mortem disclosure of an infected ventricle was a great surprise. No cultures were taken, and the pus may have been sterile. He had received an initial injection of 750 units of antitoxic serum, and no second injection had been given. Death was unmistakably due to tetanus of the acute bulbar type, possibly from an entry of toxin by way of the divided seventh and ninth cranial nerves in the deep cervical wound.

As stated, the cases with *parietal* penetration showed by far the highest mortality, for even excluding the six ventricular cases, there were 8 deaths, with only 2 recoveries. One of the fatal cases (Serial No. 7) was cited in the introductory note as an example of the early surgical failures: for only three of the first ten cases in the series with dural penetration recovered, and five fatal parietal cases occurred in the first two weeks of the service, before our technical measures had been perfected. This element must be taken into consideration in pointing out the supposed unfavourability of these parietal penetrations.

The first case died from hæmorrhage around the brain stem, as follows.

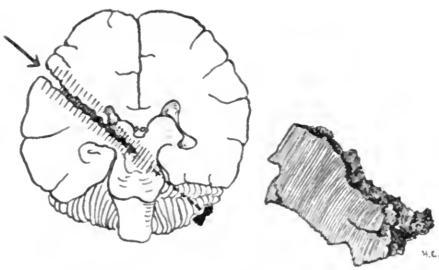


FIG. 571.—*Case* 58. Showing projectile (natural size), and course.

Case 58.—Sgt. J. C. (Serial No. 8).

July 29, 1917.—Unconscious, with actively bleeding left posterior parietal penetration.

Operation.—Bleeding vessel on cortex clipped. Respiratory failure four hours later.

Autopsy.—A 6·5-grm. shell fragment with burnished corners had penetrated the pons and cerebellum, and lay in the opposite posterior fossa, where extensive hæmorrhage had occurred (*Fig.* 571).

The next case is more typical of these older histories. It is one of the four in the entire series that died after evacuation. The man was sent down doing well after three weeks, but with a small fungus, and died in England three months later.

FIG. 572.—*Case* 59. 3-grm. projectile with polished edge (natural size).

Case 59.—Pte. E. F. (Serial No. 23).

Aug. 1, 1917.—Left mid-Rolandic penetration by shell fragment: brain extruding. Lying out 30 hours. Stuporous; right hemiplegia and aphasia, with facial epilepsy.

Operation.—Incomplete cleansing of track, though small 3-grm. projectile was removed (*Fig.* 572). Closure. Wound opened third day owing to sepsis. Eusol irrigation.

Evacuated 21st day in good condition, with small clean healing fungus. Secondary operation in England for abscess, followed by meningitis and death on Oct. 30.

We come to another familiar sequel of an imperfectly treated case—namely, rupture of an abscess into the ventricle.

Case 60.—Pte. J. S. (Serial No. 26).

Aug. 1, 1917.—Ragged wound of entry, left fronto-parietal region, with multiple wounds of shoulder and leg. *X* rays show two fragments deep in brain. Aphasia.

Operation (24 hours).—Incomplete toilette of pulped brain; superficial missile removed. Closure.

Condition excellent for two weeks; external wound healed per primam. About to be evacuated. Aug. 16.—Sudden upset, with headaches, slow pulse, choked disc, dilated pupils; temperature remains normal. Wound re-opened, and two pieces of bone recovered from track (cultures show pneumococcus). Death in 24 hours (15th day).

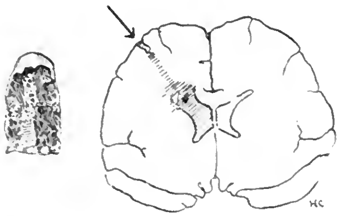


Fig. 573.—*Case* 60. 0·7-grm. projectile (natural size), with abscess rupturing into ventricle.

Autopsy.—Abscess containing small 0·7-grm. shell fragment and one bone fragment (*Fig.* 573), with rupture into ventricle. No leptomeningitis. Missile showed burnished surface.

Another example from early in the series with insufficient wound treatment follows.

Case 61.—L.-Cpl. W. I. (Serial No. 33).

Aug. 3, 1917.—Lying-out case; maggoty wounds over left upper Rolandic area; brain extruding. Right hemiplegia. *X* rays show two defects in vault, and missile in left temporal lobe, near base of skull.

Operation.—Wounds excised; some bone fragments removed from brain: track irrigated. Flap closure.

Wound sepsis, with fungus difficult to treat under flap; eusol dressings. Death 6th day.

Autopsy.—General basilar meningitis. Track through the left hemisphere to temporal lobe: a 1·9-grm. missile (*Fig.* 574) lying free in temporal fossa (small shell fragment with highly burnished surface and angles).

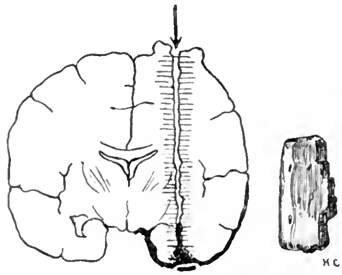


Fig. 574.—*Case* 61. 1·9-grm. projectile (natural size), traversing hemisphere.

The following shows how a very severe trauma with an apoplectic effect may be produced by a very minute fragment of shell.

Case 62.—Pte. G. W. J. (Serial No. 110).

Sept. 9, 1917.—Deeply unconscious: pulse 112; penetration in the left lower parietal region. *X* rays show F.B. on opposite side near skull.

Operation (24 hours).—Novocain. Thorough toilette, and removal of many large clots from track in left hemisphere down to falx, which blocks catheter.

Consciousness not regained; marked rise in temperature. Lumbar puncture: bloody fluid, sterile on culture. Death after 48 hours.

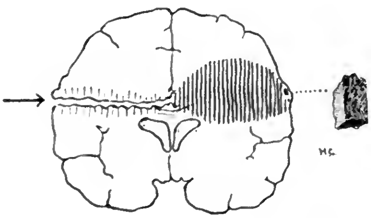
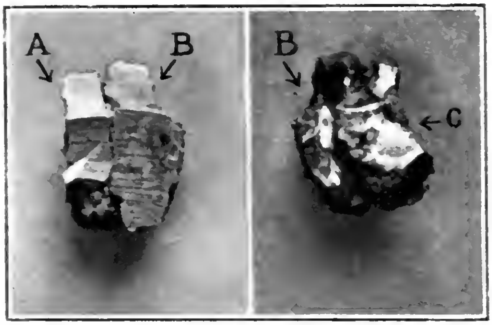


Fig. 575.—*Case* 62. Extensive damage from small 0·4-grm. missile in course through brain.

Autopsy. — Track from left precentral gyrus across brain, grazing falx, to right angular gyrus, where small 0·4-grm. shell fragment (*Fig.* 575) lies 1 cm. from surface. Extensive clot from injured vessels in great fissure fills track in right hemisphere. Ventricles free. No meningitis. Extensive thrombosis of sinuses.

A bilateral operation should doubtless have been performed, with removal of the large clot and treatment of the track in the right hemisphere as had been done in the left.

In the next case, a left parietal penetration, the chief interest lies in the behaviour of the projectile, which proves to have been a shell fragment of 7 grm. which penetrated the helmet and split into three fragments (cf. *Case* 52): two of them were deflected into the left temporal fossa without cranial injury; the third, a 1·5-grm. piece, traversed the entire brain and lay in the posterior cerebellar fossa. This fragment was not burnished, whereas the other two had a smoothly-rubbed surface evidencing a helmet penetration. Not until it was observed that the fragments fitted perfectly together was this explained, for the bit which traversed the cerebrum constituted the side of the original piece away from the surface of impaction (cf. *Figs.* 576, 577, 578).



FIGS. 576, 577.—*Case* 63. Showing (slightly enlarged) three fragments A, B, and C (cf. *Fig.* 578), fitted together as in original missile. *Fig.* 576. —Unburnished surface with penetrating fragment A; *Fig.* 577.—Burnished surface.

Case 63.—Pte. B. B. (Serial No. 161).

Sept. 30, 1917.—Deeply unconscious. Two cranial wounds: one, severe gutter type of left temporal region; the other, penetrating type of right parietal. *X* rays show one missile in posterior fossa of skull, and two fragments supposedly in the temporal lobe.

Operation.—Temporal wound proved superficial: no fracture; two fragments (5·5 grm.) removed from deep in temporal fossa. Penetrating wound drained; no attempt at missile extraction: dichloramine-T.

Post-operative Course.—Epilepsy: wound opened 4th day: cultures sterile. Very little improvement in condition. Death on 6th day.

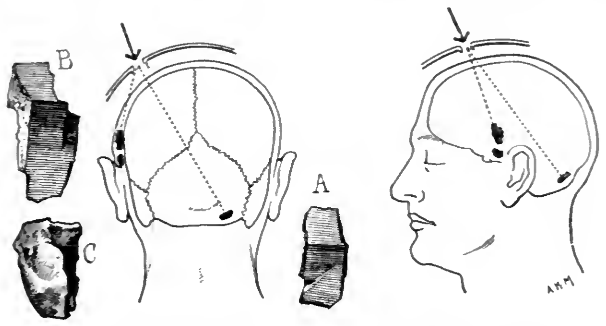
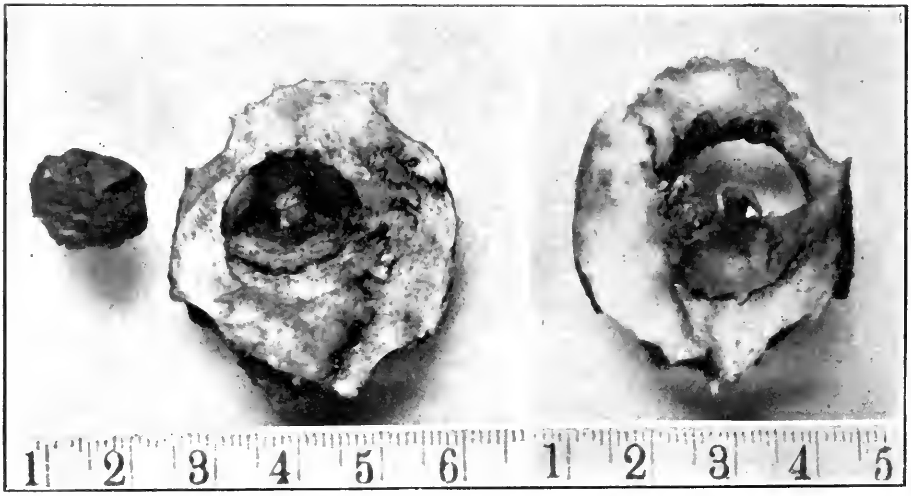


FIG. 578.—*Case* 63.—Showing three missiles (natural size), and course through helmet (cf. *Figs.* 576 and 577).

Autopsy.—Extensive subdural clots over right cerebral hemisphere and in cerebellar fossa. Track passes (*Fig.* 578) through tentorium to cerebellum, where a 1·5-grm. fragment of the original missile lies in a clot near lower surface of lobe. No meningitis.

One may be very much deluded by the apparent well-being of a patient and by the excellent appearance of the outer wound, and so regard the case

as a suitable one for evacuation. The explosion may either be sudden or with some warning. In the following case the warning rise in temperature



FIGS. 579, 580. *Case* 64. Trephine block over occipito-parietal suture; 3-grm. missile removed by magnet at later session.

due to an abscess from a retained missile passed unnoticed, and the wound was re-opened too late.

FIG. 581.—*Case* 64. Wound on second day (cf. *Fig.* 582).

It is this sort of experience which, to my thinking, has given the bad reputation to transportation in the ambulance trains. Complications of this kind cannot be attributed to transportation, for they occur only too often with the patient resting quietly in a hospital bed.

Case 64.—Pte. W. O. (Serial No. 170).

Oct. 4, 1917.—Unconscious; no history obtained. Penetrating wound of right parietal, with missile 5 cm. deep. Apparent left hemiplegia.

Operation (after 15 hours).—Tripod incisions; trepanation *en bloc* (*Figs.* 579, 580). Large blood-clot, disorganized brain, and bone fragments evacuated. Missile retained.

Post-operative Course.—Good recovery: consciousness regained on 3rd day: left hemiplegia revealed: perfect wound healing (*Figs.* 581, 582). Temperature normal till 9th day, when a slight rise (*Fig.* 583). Abscess suspected: wound re-opened: softened brain (cultures: *B. proteus*): cavity communicating with ventricle. A 3-grm. shell fragment removed by magnet (culture gives filamentous organism in chains). Dichloramine-T. Death 12th day.

Autopsy.—Local abscess insufficiently drained.

FIG. 582.—*Case* 64. Perfectly healed external wound on fifth day.

The two fatal *frontal* cases follow. The first is the only case in the group which definitely died from pneumonia, a fact the more remarkable in view of the respiratory difficulties so often present, and the amount of exposure so often endured. This, in general, speaks well for the routine adoption of local anæsthesia: but, even so, it is important to warn sisters and orderlies against efforts to force fluids on conscious or semi-conscious patients.

Case 65.—Sgt. McC. (Serial No. 53).

Aug 16, 1917.—Profoundly unconscious: shock: pulse 90. Penetrating wound of left frontal: brain extruding. *X* rays show fragments of distorted lead shrapnel ball. Choked disc: right hemiplegia.

Operation (15 hours).—Trepanation *en bloc*. Evacuation of large clot from lobe, and removal, from depth of cavity, of distorted shrapnel ball and several fragments of inner table. Closure.

Post-operative Course.—Jacksonian fits in right face. High fever: pneumonia. Death 4th day.

Autopsy.—Considerable widespread contusion of left hemisphere: wound clean: no evidence of infection. Inhalation pneumonia.

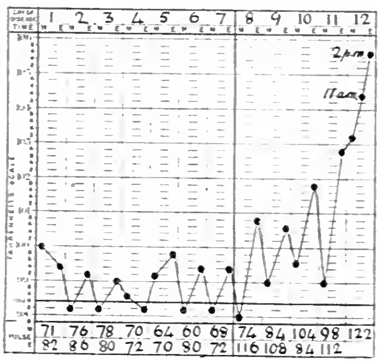


FIG. 583.—Temperature chart of *Case* 64.

The last of these cases was discharged from the casualty clearing station apparently in safe condition, though with a small well-granulating fungus.

Case 66.—Pte. E. W. (Serial No. 198).

Oct. 20, 1917.—Penetration of helmet: wound of right forehead: brain extruding. Good condition.

Operation.—Usual procedure: an 8·5-grm. shell fragment (*Fig.* 584), showing evidence of helmet penetration, removed with bits of bone from depth of 5 cm. in hemisphere. Closure, with gutta-percha wick.

Post-operative Course.—Wound infected, requiring re-opening and drainage (cultures: staphylococci and coliform bacilli). Fungus. Wound clean, and granulating well. Normal temperature (*Fig.* 585). Evacuated Nov. 5 (17th day).

Subsequent Report.—Nov. 18, No. 3 General Hospital.—Letter announcing death from meningitis.

FIG. 584.—*Case* 66. 8·5-grm. shell fragment (natural size).

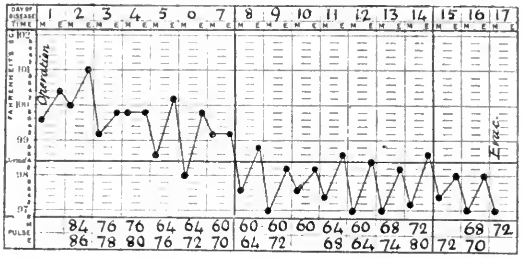


FIG. 585.—*Case* 66. Temperature irregular, tending to subnormal.

Group VI.—VENTRICULAR PENETRATION BY BONE FRAGMENTS OR PROJECTILE.

We have come to one of the most serious of complications of a penetrating wound—the opening of the ventricle or the traversing of the ventricle by the missile or by bone fragments.

Emphasis has been laid by all on the fact that the prognosis in head injuries, so far as infection is concerned, chiefly rests on whether or not the dura is intact. It has been shown, however, that minor punctures of the dura (*Group III*) are not necessarily accompanied by a bad prognosis, for, contrary to the general view, a fatal meningitis which spreads from the area of penetration is comparatively rare. Still more serious are the lesions (*Groups IV* and *V*) in which fragments, often soiled, are driven into the cerebral substance, and if not completely removed leave an infected track, with swelling and extrusion of the œdematous brain through the dural opening and external wound—the all too familiar fungus cerebri. In the course of time, either the suppurative process finds its way into the ventricle, or the advancing fungus distorts the hemisphere and draws out the ventricle, which ruptures into the infected track. Both are equally bad; examples of both sequels occurred in the series.

But far worse in their prognosis appear to be the penetrating wounds which, regardless of their point of entry, have primarily opened the ventricle, with the resultant probability of an early infection of the cerebrospinal fluid at its very source. It is for this reason that these cases have been put in a separate category. Some have gone so far as to regard them as hopeless from the outset, and have therefore eliminated them from their operation statistics. But, bad as they are, they are not entirely hopeless, as we shall see.

It is quite probable that a number of cases in *Groups IV* and *V* may have recovered with an opened ventricle, the condition not having been recognized at operation. However, with the catheter method of treating the track, it

would be hardly possible to overlook a ventricular penetration, unless all the fluid had escaped before the operation: this is improbable, for cerebrospinal-fluid leakage in a case with acute traumatic hernia cerebri is unusual.

Ventricular penetration, as already stated, has been verified at operation, or autopsy, or both, in 30 cases. The lesion had been caused by indriven bone fragments without accompanying projectile in 14 cases, of which 8 made perfect recoveries. It had been caused by the entry or passage of the projectile itself in 16 cases, with no recoveries, the condition in about half of them having been first disclosed at autopsy.

Inasmuch as the cases which have been put in this *Group VI* are, so far as the mechanism of the injury is concerned, of the two definite types considered in the preceding sections—one a tangential wound, usually parietal; the other a direct penetration, most often temporal—the facts concerning the incidents of the injuries have been assembled with the cases comprising *Groups IV* and *V* of the preceding sections.

Type A.—The Ventricle Penetrated by Bone Fragments.

We shall consider here the 14 cases of ventricular penetration by indriven bone fragments—usually, though not always (cf. *Case* 73), fragments from the inner table.

1. The Recovered Cases.—The first two examples were of the type

Fig. 586.—Parieto-temporal penetration (Serial No. 126).

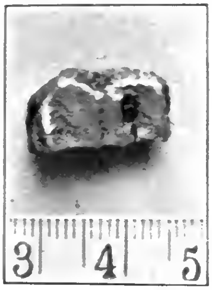


Fig. 587.—4·8-grm. missile showing edges burnished by helmet.

with the foreign body lodged in the area of cranial depression. The earliest example (Serial No. 52) has no special point of interest, aside from the fact that the catheter passed along the track from the right posterior parietal region, entered the ventricle at a depth of 6 cm., and fragments of bone were removed from this depth. It was a flap operation according to Colonel Sargent's principles, and the patient has made a perfect recovery.

The second case was also of the penetrating type (Serial No. 94), with entrance in the parieto-temporal region (*Fig.* 586) the missile (*Fig.* 587) near

the surface, but with three fragments of the squamous bone indriven to the ventricle, which was emptied through the catheter in the process of cleaning the track. There were no secondary complications, and the patient has made a good recovery, with slight residual paraphasia.

The remaining cases all had wounds of gutter type, and the conditions were somewhat more difficult.

Case 67.—Sec.-Lieut. K. G. (Serial No. 106). **Frontal gutter wound, with bone fragments indriven to ventricle. Pneumococcus infection. Recovery.**

Admission, Aug. 22, 1917, 1.30 p.m.—Six hours previously had received injury from rifle ball which perforated helmet. Dazed, but managed to walk to A.D.S., where he lost consciousness.

General Condition.—Poor: stuporous, but can be roused. Resuscitation ward for 10 hours, with improvement.

FIG. 588.—*Case* 67. Characteristic *x*-ray picture showing thirteen indriven bone fragments.

FIG. 589.—*Case* 67. Bone fragments removed (cf. *Fig.* 588).

Wound.—Open, gutter type; parieto-frontal region; transverse, slightly more to right, but crossing mid-line. Brain exposed and extruding. *X*-ray report: "thirteen indriven bone fragments" (*Fig.* 588).

Neurological Findings.—Mentality apparently unimpaired (subsequently no recollection of events from time of losing consciousness till in ward after operation). Disc margins and cup obscured. No paralysis. Deep reflexes: right, normal; left, not obtained.

Operation, 11 p.m. (*circa* 18 hours).—Novocain. Excision, first, of wide gutter wound of scalp, then of bone. Exploration of sinus with soft catheter detects fragments: track leads into ventricle. Fourteen bone fragments recovered (*Fig.* 589) track cleaned; ventricle emptied; complete collapse of fungus. Partial closure by plastic flap; lateral drains. Urotropin.

Post-operative Course.—Slight rise in temperature for five days (*Fig.* 590). Cerebrospinal leak for two days, followed by dull headache. Aug. 26.—Lumbar puncture: 45 c.c. yellowish fluid under tension (culture: pneumococcus). Aug. 28.—Second lumbar puncture: 2 c.c. clear fluid, no tension (culture: a few diplococci remain). Sept. 4.—Granulating wound over the denuded area of

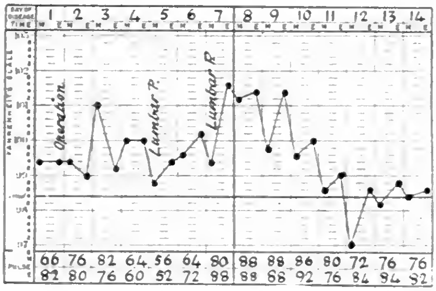


FIG. 590. Temperature chart of *Case* 67.

pericranium (*Fig.* 591): the flap over defect solid and without protrusion; temperature normal. Evacuated.

Subsequent Reports.—Nov. 6 (by letter).—"Very fit in all respects: no headaches." Jan. 6 (by letter).—Given six months' leave. Occasional slight headache; general health perfect.

FIG. 591.—*Case* 67. Showing flap operation with granulating area on fourteenth day.

The recovery in this case was doubtless due to the thorough cleansing, with removal of all the disorganized brain and bone fragments: for though it was before the principle of suction came to be regularly practised, over two hours were expended on the operation, most of the time being devoted to the toilette of the track.

Another wound in the same situation and of a very similar nature (Serial No. 108), in another officer, was similarly treated at about this time by my assistant, Captain Horrax, with an equally good end-result, though the wound had to be re-opened owing to the retention of one or two fragments of bone, and in consequence a cerebrospinal-fluid leak was established which persisted for a week.

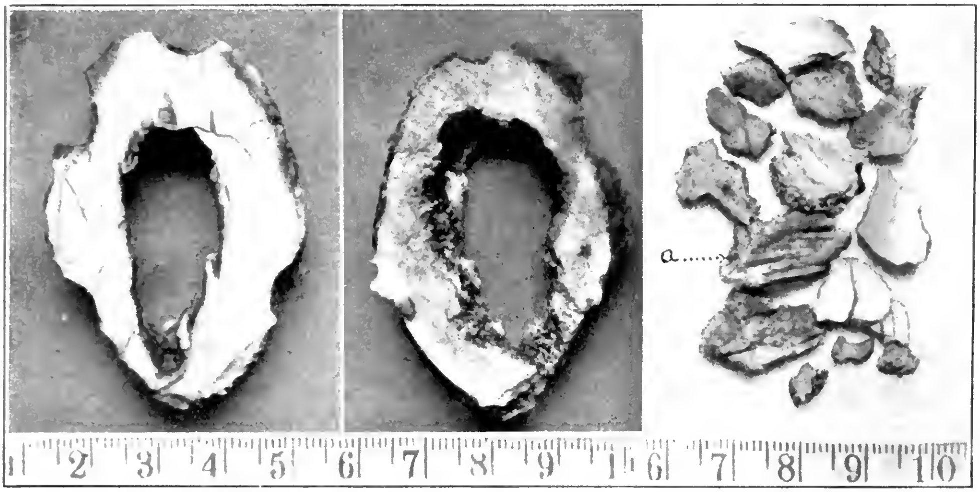
The following case is remarkable in that it was possible to make a presumptive diagnosis of ventricular penetration owing to the peculiar position of the bone fragments as shown by the stereoscopic Röntgengrams.

Case 68.—L.-Cpl. E. W. P. (Serial No. 154). **Left parieto-frontal gutter fracture, with showered fragments penetrating ventricle: some fragments, free in ventricle, retained. Recovery.**

Admission, Sept. 29, 1917, 1.40 a.m.—History of having been wounded at 7 a.m. the previous day, a fragment of shell penetrating helmet. Temporary unconsciousness. No attempt to walk. Headache. Vomiting.

General Condition.—A little hazy, but conscious and rational. Warm. Pulse 80.

Wound.—Ragged; gutter type; left parieto-frontal; longitudinally disposed; brain extruding. The *x* rays show stereoscopically a cluster of bone fragments about 7 cm. inwards from the wound of entrance, and another cluster well back in the occipital region about in the situation of the posterior horn of the left ventricle.



FIGS. 592, 593, 594.—*Case* 68. Bone disc showing gutter wound, with complete separation of fragments from inner table. Note scratching of some fragments, e.g., (*a*), of outer table by passing missile.

Neurological Findings.—Memory imperfect: orientation poor. No aphasia (right-handed). Weakness and apparent hypæsthesia over entire right side. Deep reflexes normal on left; exaggerated on right; without clonus, though with dorsal toe-response.

FIG. 595.—*Case* 68. Wound showing flap closure with small defect at angle: second day.

Operation, 2 p.m. (31 hours).—Novocain. Excision of wide gutter wound, and preparation for closure by lateral flap (cf. *Fig.* 595). Trepanation *en bloc* (*Figs.* 592, 593); no adhering fragments of inner table—all showered through dural opening, from which a large amount of clot and pulped brain was expelled by getting patient to cough. On suction of the sinus a large amount of bloody cerebrospinal fluid was withdrawn, and the mass of bone fragments was detected at a depth of 5 cm. Eight sizable fragments of both tables were picked out, and several smaller ones withdrawn in the eye of

the catheter (*Fig.* 594). Finally, a track about 2 cm. in diameter, leading from the surface to the ventricle, lay wide open. The catheter could be inserted into the ventricle a distance of 10 cm., and the cavity was irrigated with warm salt solution, but without washing out the posterior fragments (cultures taken from the ventricle grew staphylococci). About 1 c.c. of dichloramine-T was left in the track and ventricle, and the scalp was closed in layers.

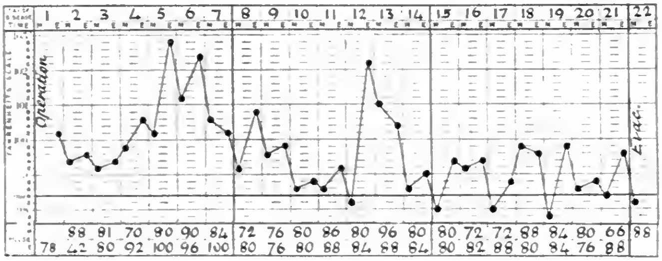


Fig. 596.—Temperature chart of *Case* 68.

Sept. 30 (*Fig.* 595).—Sutures removed. General condition unexpectedly good. Lumbar puncture: 35 c.c. slightly yellow fluid (cultures sterile). Oct. 6.—No symptoms to account for recent periods of fever (cf. chart, *Fig.* 596). Second *x*-ray examination, showing retention of deeper mass of bone in unchanged position. Oct. 19.—Complete amnesia for period between wound and operation. Otherwise no mental or other neurological abnormality observable. Evacuated.

Subsequent Reports.—Feb. 1, 1918 (by letter).—Red Cross Hospital in Chester for three weeks; thence to Cheshire Hospital. No paralysis: feels quite well aside from some "headache when he catches cold." Hopes to go before Board, get discharge, and return immediately to former occupation.

The succeeding case, though of very similar type, may also deserve recording in some detail.

Case 69.—Sgt. F. G. J. (Serial No. 160). **Right frontal gutter fracture, with fragments showered into ventricle. Usual toilette, with emptying of ventricle. Closure. Recovery.**

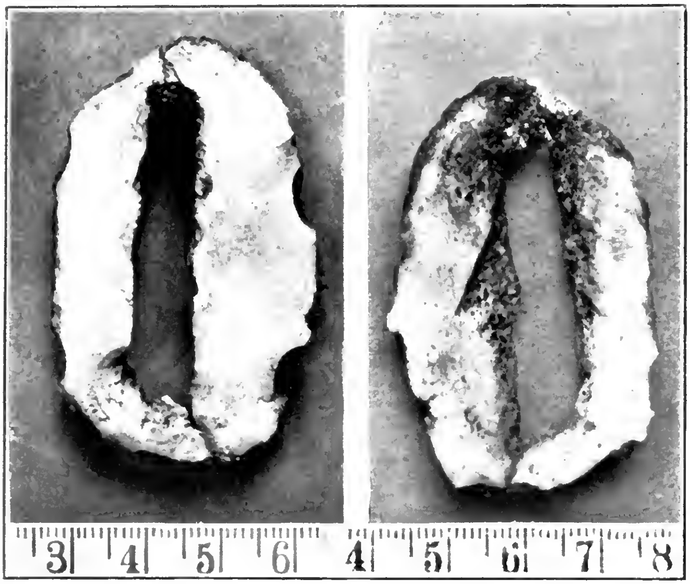

Fig. 597.—*Case* 69. Wound before operation.

Admission, Sept. 30, 1917, 2.30 a.m.—History of having been bombed during an air raid.

General Condition, 9 a.m.—Resuscitation ward during night. Conscious; fairly rational. Remembers the raid, and being without a helmet: no recollection of subsequent events. Pulse 66.

Wound.—Longitudinal gutter type, right upper frontal (*Fig.* 597): brain extruding. *X*-ray (stereoscopic) report: "Bone defect, with indriven fragments in two groups, one possibly in ventricle."

Neurological Findings.—Disoriented for time and place. Weakness of left arm and leg. Deep reflexes: brisk; equal; no clonus.



FIGS. 598, 599.—*Case* 69. Typical gutter fracture, without adherent bone fragments.

Operation, 11 a.m. (10 hours).—Novocain. Tripod ('Isle of Man') incisions encircling gutter wound. Trepanation *en bloc* (*Figs.* 598, 599). No bone fragments adherent: all indriven. Laceration of dura, 3 cm. long. Extensive pulping of lobe, with bloody fluid obviously coming from ventricle. Much disorganized brain and clot irrigated and sucked out; much more expressed during act of vomiting. Fragments palpated by catheter at depth of 5 cm.; picked out with duck-billed forceps. Collapsed brain, and wide open track communicating with ventricle. Dichloramine-T. Edges of unexcised and lacerated dural margin drawn loosely together with two fine silk sutures. Closure of scalp in layers, with no drain. Urotropin.

FIG. 600.—*Case* 69. Wound on fourth day (cf. *Fig.* 597).

Oct. 1.—Some bloody and oily cerebrospinal fluid from between sutures (culture: no growth). Lumbar puncture: 20 c.c. of blood-stained fluid (culture: no growth). Temperature normal. Persistent hiccoughs; otherwise condition excellent. Oct. 2.—Temperature elevated, 101°. Lumbar puncture: 20 c.c. fluid, less blood-stained (culture sterile). Oct. 4.—Continuous hiccoughing for past two days. Temperature 103°, but no symptoms to account for it: feels well. Wound perfect: sutures removed (*Fig.* 600). Oct. 6.—Sixth day of uninterrupted hiccoughing. Says he has had similar attacks before, his mother also. Oct. 14.—

Cessation of hiccoughs on 7th day. Normal temperature (*Fig.* 601). Condition excellent. No mental impairment. Wound solid (*Fig.* 602). Repeated x-ray examinations show two small fragments of bone remaining in track: none in ventricular region. Evacuated.

Subsequent Reports.—No. 11 General Hospital.—No neurological symptoms. Evacuated to England Oct. 22. Dec. 10 (by letter from King George Hosp.).—Up and about: no headaches whatever: no other symptoms so far as he can see. Feb. 20, 1918.—Has received discharge; given a skull cap with steel plate; does not know why. Expects to return to work with former firm of solicitors: thinks his memory a little defective.

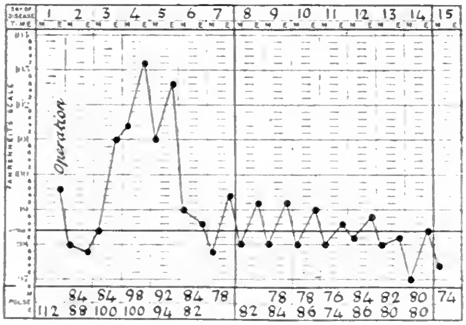


FIG. 601.—*Case* 69. Temperature chart of case with opened ventricle.

FIG. 602.—*Case* 69. Wound on twelfth day.

At times the loss of substance from the scalp is so great, or the scalp so densely adherent in the subaponeurotic layer, that a closure by plastic of the defect is most difficult or almost impossible. In ordinary cases it is simpler under these circumstances to leave the defect directly over the operative area, and permit a small fungus to develop: but in case the track communicates with the ventricle, one must close the immediate defect by some form of plastic at all hazards. The following case is an example of this.

Case 70.—Sgt. F. W. D. (Serial No. 184). **Fronto-parietal gutter wound; mild sinus syndrome; bone fragments penetrating ventricle. Recovery.**

Admission, Oct. 12, 1917.—History of having been hit about 6.30 a.m., shortly after going forward in an attack. Wearing his helmet. Stunned: found he could not walk: managed to crawl back to aid post.

General Condition.—Conscious: pulse 72: mentality unimpaired.

Wound.—Gutter type: longitudinal, 8 cm. long, just to right of mid-line at anterior parietal vertex. Brain extruding. X-ray report: "Fracture, with deeply indriven bone fragments."

Neurological Findings.—Complains of weakness and stiffness in legs. Moderate spasticity present, equal on the two sides. Deep reflexes brisk to exaggeration, but no elonus.

Operation, 4 p m. (10 hours).—Novocain. Excision of large greatly-soiled scalp wound, disclosing a polar opening in skull measuring 2·5 by 1·5 cm., with five meridional fissures running from it. Trepanation *en bloc*. No adherent fragments of inner table; all showered through tear in dura just to right of longitudinal sinus. Usual toilette of track; ten fragments (*Fig.* 603) of both outer and inner tables recovered from depth. On releasing largest fragment (broth culture gave staphylococci), a gush of bloody cerebrospinal fluid occurred, with complete collapse of brain, leaving track wide open. Dichloramine-T. Ragged tear in dura drawn together with two fine silk sutures. Area of defect closed with elaborate S-shaped plastic (cf. *Fig.* 605), leaving an area of denuded pericranium fore and aft.

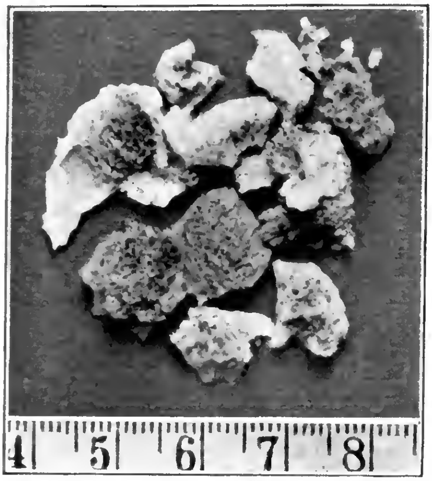


FIG. 603.—*Case* 70.—Fragments removed from ventricle and track.

Post-operative Course.—Despite a superficial staphylococcus infection, the flaps held. Highest temperature 100·2° (*Fig.* 604). On second day sutures removed (*Fig.* 605). The spasticity of the legs subsided gradually, more rapidly on the left than the right. (The contused area undoubtedly present over the corresponding part of the opposite hemisphere was slower in regaining its function than the pulped area treated by suction in the right hemisphere.) The two granulating areas (*Fig.* 606) were planted with Reverdin grafts on Nov. 2. Evacuated Nov. 5.

Subsequent Report.—Nov. 30.—Evacuated to England from No. 16 General Hospital; wounds healed. Feb. 21, 1918.—Discharged from service; some dizziness and headaches.

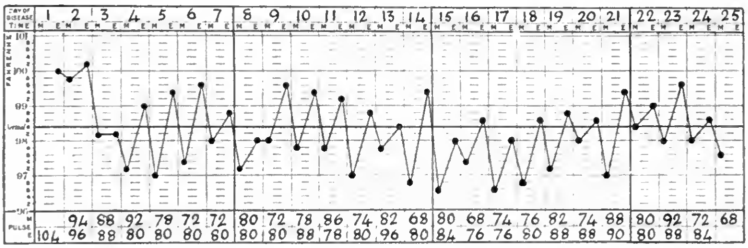


FIG. 604.—Temperature chart of *Case* 70.

The story of the last of these eight patients (Serial No. 185) with recovery after penetration of the ventricle by bone fragments, need not be recorded in full, as it is almost the counterpart of *Case* 69, except that the wound was lower in the frontal region. The patient has received his discharge from the army, and writes that he is practically free from all symptoms.

2. **The Fatal Cases.**—The first of these, the second in the operative series, shows again how imperfect were our early methods of treatment.

Case 71.—Dvr. A. A. E. (Serial No. 2).

July 25, 1917.—Patient semi-conscious; penetrating wound of upper left Rolandic region; brain extruding; superficial projectile; indriven bone. Right hemiplegia, with exaggerated reflexes.

Operation.—Ether. Excision of scalp wound and of fungus. Bone opening enlarged with rongeurs, exposing 2-cm. margin of intact dura. A few bone fragments picked out of track. Closure of defect by plastic flap, with lateral drain. Subsequent restlessness, requiring much morphia: unconsciousness: fever: death in 48 hours.

FIGS. 605, 606.—*Case 70.* Showing wound on first dressing (second day), and two weeks later.

Autopsy.—The flap of scalp covers a badly infected, stinking fungus with gas bubbles. Section of the brain exposes a softened cavity the size of an egg, containing disorganized brain and pus with bone fragments, some of which have been driven into the badly infected ventricle. Cover-glass preparations show abundant organisms of *B. Welchii* type.

Four other fatal cases with wounds of the parietal vault occurred later in the series. The first of them follows.

Case 72.—Gnr. J. G. (Serial No. 96).

Sept. 3, 1917.—Admitted in critical condition, with a cerebral herniation occupying a large parieto-frontal gutter wound involving scalp and cranium (*Fig. 607*). The skull was very rich in diploë, and there were no plates of inner table adherent to the bone disc. The detached fragments were small, and all showered. Three meridional lines of fracture radiated from the bone defect. Death on the 4th day, though the lumbar fluid was found sterile the day before.

Autopsy.—A purulent ventriculitis and encephalitis (*B. Welchii*).

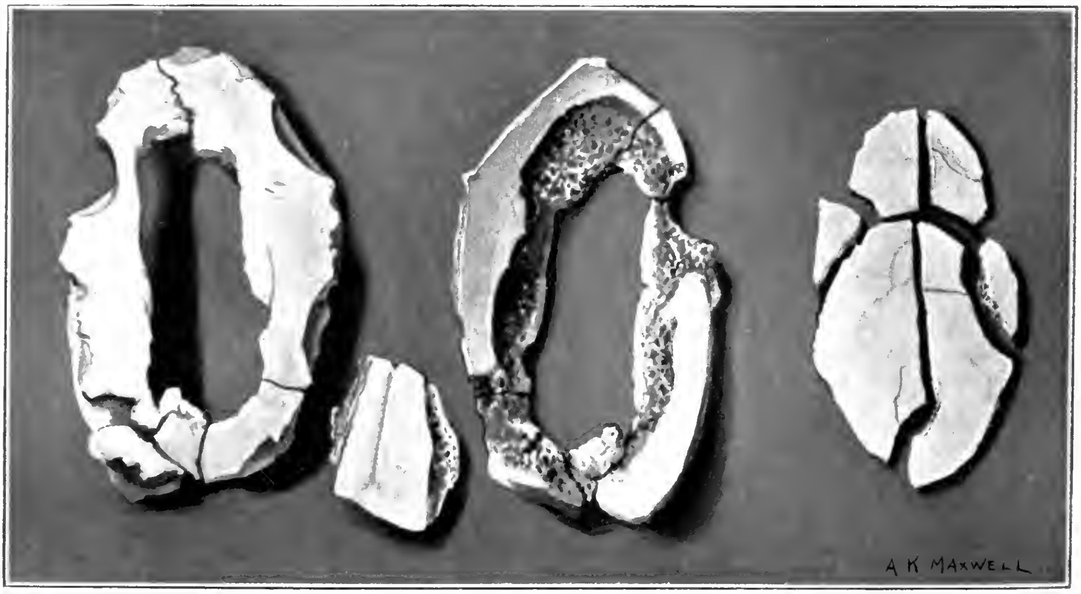
The effect on the skull of these large gutter wounds, all produced by a similar form of tangential injury, varies considerably from case to case, depending greatly upon the structural characteristics of the individual calvarium. In the following, as in *Case* 34 (*Fig. 523*), the large plates of inner

table, though fully detached, remained adherent to the dura, but broke in the middle like a trap-door, and permitted the fragments of outer table to be indriven to the ventricle.

FIG. 607.—*Case* 72. Showing characteristic gutter wound from both aspects.

Case 73.—A German prisoner (Serial No. 130).

Sept. 20, 1917.—Wounded by rifle ball 48 hours before operation: not wearing his helmet. Gutter wound, right parietal; brain extruding. Left hemiplegia.



FIGS. 608, 609, 610.—*Case* 73. Outer and inner aspects of block, with fragment of external table, which was driven between the plates of inner table into ventricle.

Trepanation *en bloc* (*Figs.* 608, 609). The large leaves of broken inner table very adherent to dura (*Fig.* 610). Between them a fragment of outer table had been driven into brain, opening ventricle. Careful toilette of track. Dichloramine-T. Partial closure, with direct drainage, owing to obvious infection. Death in three days, after sudden rise in temperature to 105°.

Autopsy.—Ventriculitis; meningitis; gas infection of brain.

Another parietal fatality (Serial No. 187) was very similar to the foregoing. The man had been lying out for three days; the wound was dirty; bone fragments had been driven to the ventricle; death occurred from intracranial sepsis on the third day. The results in these delayed cases furnish the best argument for the earliest possible operation in penetrating wounds.

The following, the single occipital case in this group, is lamentable from the fact of an incomplete though early operation which failed to secure all fragments of bone. Had the man been evacuated on or about the tenth day, when doing apparently well, his upset would naturally have been attributed to the effects of transportation.

Case 74.—Pte. E. F. (Serial No. 142). **Occipital gutter wound. Ventricle penetrated. Incomplete operation. Death in two weeks from sepsis.**

Admitted Sept. 27, 1917, 3 a.m.—Wounded 6 hours before: wearing helmet. General condition fair, though drowsy and unresponsive.

Wound.—Gutter type: right parieto-occipital: brain extruding.

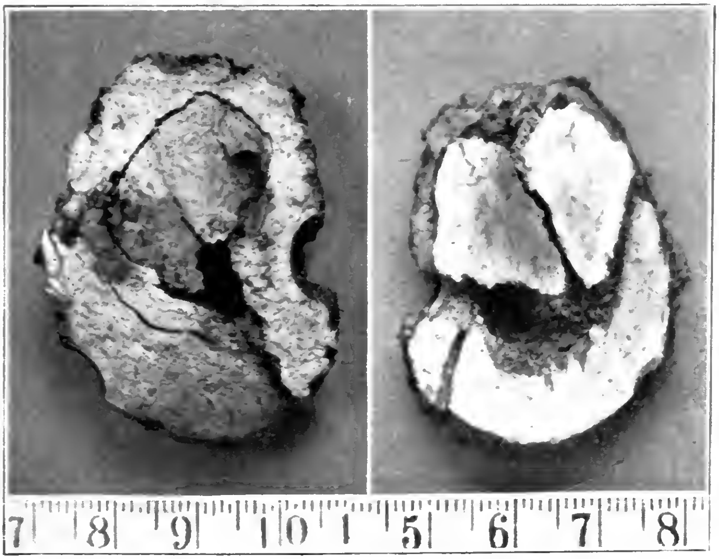


Fig. 611.—*Case* 74. Outer and inner aspects of trepanation block, showing oblique penetration.

Neurological Findings.—Deep reflexes hyperactive; otherwise nothing made out. No hemianopsia.

Operation, 10 a.m. (13 hours).—Novocain. Tripod excision of scalp wound: trepanation *en bloc* (*Fig.* 611): one large fragment of inner table driven edgewise through dura to ventricle: no other fragments recovered. Usual toilette, with dichloramine-T. Incomplete closure, with central drain.

Subsequent Course.—External wound (*Fig.* 612) appeared well; no discharge of cerebrospinal fluid. Patient was about to be evacuated on 11th day, when there occurred a sudden rise in temperature to 103° (*Fig.* 613). with signs of intracranial pressure. A fungus cerebri rapidly developed, with extrusion of remaining fragments of bone and a cerebrospinal-fluid leak. Lumbar puncture: sterile fluid. Cultures from wound: streptococci. Death, 15th day.

Autopsy.—Meningitis and ventriculitis.

FIG. 612.—*Case* 74. On tenth day, before contemplated evacuation.

Only one of the fatalities included in this group died from the effects of the trauma too early for ventricular sepsis to play any rôle.

Case 75.—An unknown civilian (Serial No. 68).

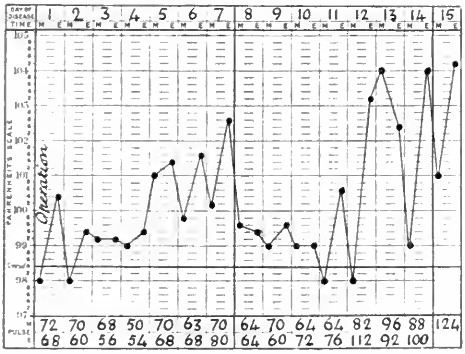


FIG. 613.—Temperature chart of *Case* 74.

Admission Aug. 20, 1917, 12.30 a.m.—Victim of an air raid; unconscious. No particulars. Gutter wound of posterior parietal region; bleeding cerebral herniation: pressure pneumonia: choked disc and rhythmic respiration.

Operation.—Confined to mere repair of external wound, with control of bleeding from superficial meningeal vessels. No return of consciousness. Death in 24 hours.

Autopsy.—A double track made by fragments of bone, one leading through posterior horn of left ventricle, tentorium, and cerebellum. Blood-clot surrounds hind-brain, and extends up over left cerebral hemisphere.

Type B.—THE VENTRICLE PENETRATED OR TRAVERSED BY A PROJECTILE.

In this type there were no certified recoveries, and the condition in most instances was a post-mortem finding. Death was due to trauma and hæmorrhage in 8 cases; to secondary infection of the cerebrospinal spaces in 7; to intercurrent causes in 1.

It is not at all improbable that in some of the patients who have recovered, with retention of the foreign body, the missile may actually have penetrated or perforated the ventricle; this can only be surmised, by the help of the three-dimensional study of the course of the projectile, aided by the *x*-ray examination in each case. It is significant, however, that among the fatalities from a lodged projectile, the post-mortem examination showed that the ventricle had been opened in slightly more than half (16 out of 31).

It is interesting to find that the projectile not uncommonly lodges in the ventricle, as though the pool of fluid serves more effectively to check its progress than the cerebral tissue. This was true in 6 of the 16 cases, and in one there were two missiles in the ventricle.

The single case in the series in which the missile, identified as being in the ventricle, was removed at operation, possibly deserves a somewhat detailed report.

Case 76.—Pte. D. Q. (Serial No. 22). **Magnet extraction, after two days, of shell fragment from infected ventricle. Irrigation of ventricle; subsidence of local infection. Death three months later from inanition.**

Admitted Aug. 1, 1917.—Wounded about 11 a.m. of preceding day: a shell fragment penetrated helmet: much bleeding from wound, but no loss of consciousness; left side powerless; not found by bearers till to-day; reached casualty clearing station at 4 p.m.; conscious, but in collapse.

General Condition, Aug. 2, 4 p.m., after 24 hours in resuscitation ward.—Conscious; warm; pulse much improved, 70; headache.

Wound.—Penetrating variety, 2 cm. to right of mid-parietal vertex; no brain extruding. X-ray (stereoscopic) report: "Small penetration: projectile in mid-brain: bone fragments in track" (*Fig.* 614).

Fig. 614.—*Case* 76. X-ray picture showing projectile in ventricle.

Neurological Findings.—Spastic left hemiplegia involving arm, leg, and face, with sensory loss over arm and leg: clonus at knee and ankle; dorsal plantar response. Left homonymous hemianopsia. Optic discs hyperæmic: blurred outlines: cups œdematous.

Operation, Aug. 2, 5 p.m. (53 hours).—Novocain. Curvilinear flap, with excision of wound: enlargement of bony opening: bleeding from longitudinal sinus on picking out superficial fragments, checked by fascial graft: lateral incision of wound in exposed dura: escape of much disorganized brain and clot. Soft catheter introduced, and at depth of 6 cm. enters ventricle: about 20 c.c. of bloody seropurulent fluid removed: culture gave abundant *B. perfringens* and staphylococci. Eusol irrigation into cavity. Several bone fragments removed from track. Insertion of

nail to ventricle, with magnet extraction of 3·8-grm. projectile (*Fig.* 615) on first trial. Small-calibre catheter left in sinus. Closure except for catheter.

Aug. 3.—Temperature 100°. Chief complaint, discomfort in paralyzed side. Some cervical stiffness. Ventricle draining well; culture No. 2: "Cocci and *B. perfringens* in abundance." Aug. 4.—Third culture from ventricle: "Cocci and *B. perfringens*." Aug. 5.—Extensive herpes labialis, with rise in temperature to 102°, but general condition appears much better; rational; talking; taking nourishment well. Aug. 9.—Has had daily gentle irrigation of ventricle through catheter, which has been retained, and has drained well; culture No. 4. Condition excellent: beginning to move fingers on left. Catheter withdrawn. Aug. 10.—Rise in temperature to 102°. (Report of culture No. 4: "Cocci persist, (?) pneumo-cocci. Bacilli rare.") Aug. 13.—Reaction following removal of drain has subsided. Possibly slight fullness in wound. Beginning return of movements in left foot. Sept. 13.—During the month's interval there were ups and downs in the man's condition, with dull and brighter periods alternating. Believing that there must either be an abscess, a ventricular hydrops, or an area of cerebral softening, several exploratory punctures were made in the hemisphere, with negative findings, the ventricle being entered on one occasion (Aug. 28) and found to contain clear sterile fluid. Oct. 4.—Temperature normal for past three weeks, but he remains for the most part dull and unresponsive, with marked inappetence. Slight movements possible in arm and leg, but very little progress being made. Evacuated (71 days).

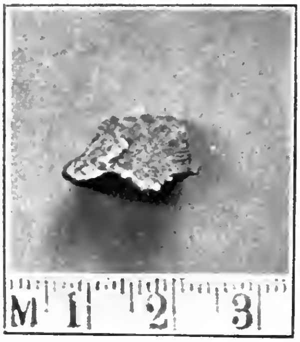


FIG. 615.—*Case* 76. 3·8-grm. fragment, with rubbed edge, removed from ventricle.

Subsequent Notes.—He reached No. 2 Canadian General Hospital in bad condition, bedsores developed, and he died two weeks after his admission.

Autopsy Note.—"Head, only, opened. The semilunar scar over the right parietal area was adherant. There was a considerable amount of scar tissue in the brain substance under this wound. The brain was pale. There was no sign of pus; no abscess, no meningitis."

Death presumably occurred from inanition, as may happen to bed-ridden hemiplegics.

Though the severity of the cerebral injury rather than the early intracranial infection accounts for the death of this man, the experience nevertheless stands as an argument for earlier operation. It is my feeling, so far as head cases are concerned, that the long period so often passed in the resuscitation ward, with the administration of warmth and stimulants, is too serious a loss of time when taken from the standpoint of the possible establishment meanwhile of a serious infection. A cranial operation under combined morphia and a local anæsthetic may be carried out at the same time that warmth, fluids, and stimulants are being administered.

The following, another early case in the series, was also delayed for long in the resuscitation ward. The ventricular perforation played an unimportant rôle, but the case is of interest from other standpoints.

Case 77.—Pte. E. B. (Serial No. 61). **Penetrating shell fragment passing from vault to base through ventricle. Operation, with missile extraction, deferred 22 hours. Gas encephalitis.**

Admission, Aug. 16, 1917, 4 p.m.—No history (helmet worn, cf. *Fig.* 617): critical condition; somnolent. Resuscitation ward 22 hours.

Wound, Aug. 17.—Lacerated, of penetrating type, just to right of mid-vertex;

brain extruding. *X* rays show shell fragment lying beside pituitary fossa, with bone fragments in its path (*Fig.* 616).

Neurological Findings.—No response to stimuli; apparent paralysis with rigidity of left side, with reflexes increased to clonus, and positive Babinski. Persistent conjugate deviation of head and eyes to right. Profuse sweating.

Operation, 1.30 p.m. (*circa* 22 hours ?).—Excision of scalp wound; trepanation *en bloc* (*Fig.* 617). Prompt extrusion of clots and disorganized brain. Catheter suction of track, with removal of the 8 fragments of bone shown by *x* rays —some withdrawn in eye of catheter. Bloody cerebrospinal fluid. Catheter enters 13 cm., and detects foreign body. Attempted magnet extraction with an intervening wire nail: first trial unsuccessful: local current switched off. In lieu of magnet a piece of small stomach tube was cut off, inserted to bottom of track, and suction applied: the missile (*Fig.* 617) was withdrawn in eye of tube (culture, reported following day: *B. perfringens*). Closure of wound by plastic method. Missile weighs 3·5 grm., and shows a burnished surface from helmet penetration.

Fig. 616.—Radiogram of *Case* 77.

Fig. 617.—*Case* 77. Bone block and missile with burnished surface.

Aug. 18.—Temperature 99°; partial return of consciousness. 11 p.m.—Sudden rise of temperature to 104°. Wound re-opened; stinking gas infection. Eusol irrigation of track continued during night. Aug. 19.—Death at 8 a.m. Temperature 107°.

Autopsy.—Extensive gas encephalitis of entire hemisphere. Track passed parallel to falx through ventricle to temporal lobe beside sella turcica. No apparent meningitis.

Despite the delayed operation, had the wound in this case been left open with direct catheter drainage, as in the preceding one, there would have been a very good chance of recovery. It is in matters of this kind when judgement is put to the greatest test—to close or not to close. It is possible that immediate cover-slip examinations of the deeper wound might serve in place of culture, a report of which means too great delay to be of influence in the question of drainage.

The remaining fatal cases in *Group VI* are as follows: 6 of them were obviously due to the trauma and hæmorrhage alone; 2 to intercurrent causes (exposure and pneumonia); the remaining 7 to sepsis, usually spreading into the ventricle.

The traumatic cases follow.

Case 78.—Capt. L. G. (Serial No. 105). **Multiple wounds; double left temporal cranial penetrations.**

Aug. 22, 1917.—No history. Terminal stage of pressure pneumonia; Cheyne-Stokes respiration. Attempted relief by operation; no anæsthetic; large clot over hemisphere: meningeal and middle cerebral vessels found injured. Temporary improvement. Death 24 hours.

Autopsy.—Track of one missile (*Fig.* 618) to ventricle; the other passes through ventricle, which is filled with blood, and lodges in opposite hemisphere; extensive subdural and intracerebral clot.

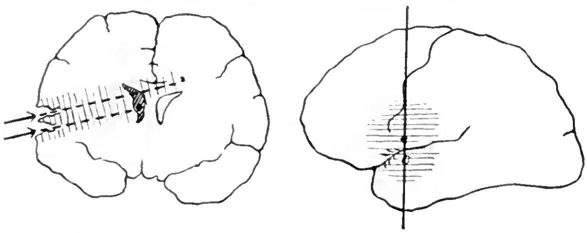


FIG. 618.—*Case* 78. Showing course of missiles.

Case 79.—Pte. J. C. (Serial No. 32). **Multiple penetrations of vertex; serious intracranial lesions produced by small projectile.**

Admitted Aug. 3, 1917.—In resuscitation ward three days unconscious, with extreme spastic rigidity. Transferred to us for operation, Aug. 6, with pulse 150, temperature 102°, respirations rhythmic. Right subtemporal decompression; no anæsthetic. Death in 6 hours.

Autopsy.—Minute perforation to left of median line: sinus uninjured. Clot over entire left hemisphere; thick clot between the two hemispheres. Track passes (*Fig.* 619) through corpus callosum, right lateral ventricle—which is full of blood—to inferior right temporal lobe, where small 0·3-grm. projectile (cf. *Fig.* 619) is lodged.

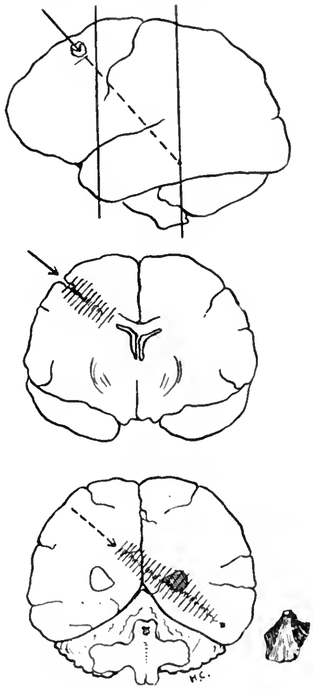


FIG. 619.—*Case* 79. Showing small missile (natural size), and course.

Case 80.—Pte. C. R. (Serial No. 39). **Penetrating wound, right fronto-temporal.**

Aug. 6, 1917.—Profoundly unconscious; pressure phenomena. Immediate operation; no anæsthetic; temporal flap; trepanation; large subdural clot evacuated; bleeding Sylvian vein clipped; closure. Death in 19 hours; no return of consciousness.

Autopsy.—Clot over hemisphere incompletely removed at operation. Track of missile: from frontal lobe diagonally into opposite ventricle (*Fig.* 620), where a 1-grm. missile with a burnished face lies free. No gross evidence of sepsis.

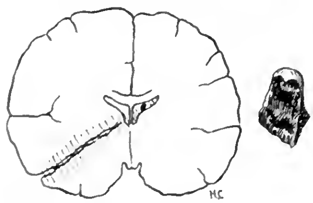


FIG. 620.—*Case* 80. Showing small missile (natural size) lodged in ventricle.

Case 81.—Pte. A. H. (Serial No. 63). **Multiple wounds, one penetrating glabella, with projectile lodged in left hemisphere under parietal eminence.**

Aug. 17, 1917.—Profoundly unconscious; pulse 60; papillœdema; complete right hemiplegia. 11 p.m.—Condition rapidly growing worse: pulse 90 and irregular; choked disc 2 D: right pupil dilated. Attempted left subtemporal decompression: no anæsthetic; film of clot over very tense hemisphere. Temporizing investigation of wound of entrance, which passed through frontal sinus. Death in 4 hours.

Autopsy.—Track of missile from frontal pole of hemisphere into left ventricle, which is distended with blood. A 2·2-grm. projectile (*Fig.* 621) lies in ventricle about opposite posterior end of the thalamus. Entire left hemisphere contused and œdematous.

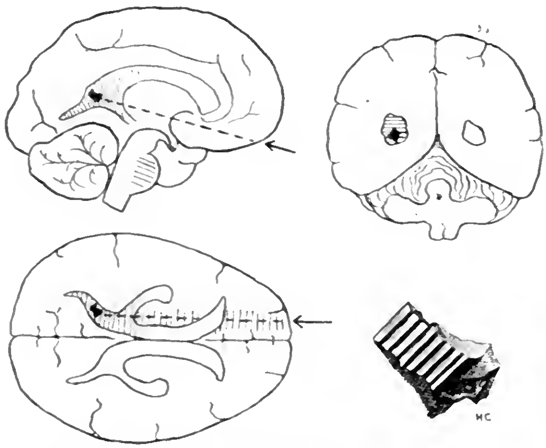


Fig. 621.—*Case* 81. Showing a 2·2-grm. missile, and course to ventricle.

Case 82.—Pte. H. L. E. (Serial No. 88).

Aug. 31, 1917.—Admitted 2 p.m. in critical condition. Large penetrating wound in mid-line at coronal suture; brain extruding. *X*-ray report: "Large foreign body at base near petrous bone" (*Fig.* 622). Resuscitation ward 21 hours. Sept. 1.—Profoundly unconscious; choked disc 1 D; typical longitudinal-sinus syndrome, with spasticities, adductor spasm, clonus, etc.

Operation.—No anæsthetic necessary; trepanation *en bloc*; careful toilette of track, with removal of deep bone fragments: catheter enters 6·5 cm. and detects missile: nail inserted: magnet extraction of 15-grm. missile (*Fig.* 623) on first trial. Consciousness not regained. Death in 24 hours.

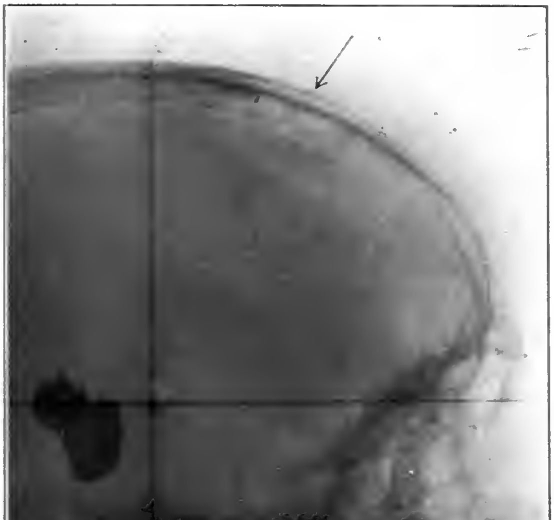


Fig. 622.—*Case* 82. *X*-ray photograph showing deep position of large missile, and characteristic track.

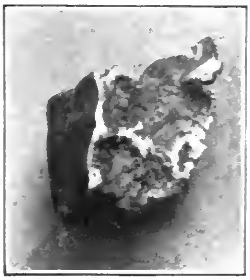


Fig. 623. *Case* 82. Missile (15 grm.) with burnished edge (natural size).

Autopsy.—Meridional fracture lines, extending to base. Track of missile crosses ventricle and enters temporal lobe. Widespread subdural hæmorrhage over left hemisphere.

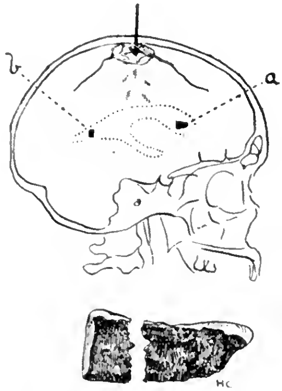


FIG. 624.—*Case* 83. Showing *x*-ray appearance, with position of two pieces of one original rubbed fragment.

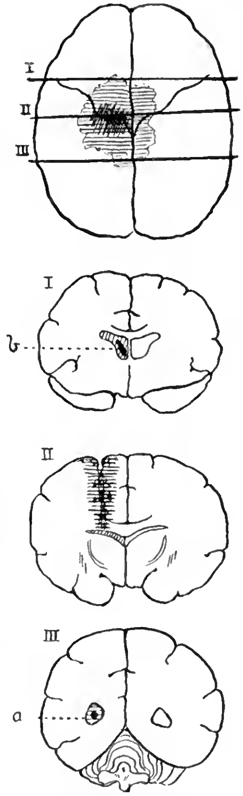


FIG. 625. — *Case* 83. Autopsy findings.

Another example, though not included in the operative series, as death took place during the preparation for operation, may be given, as it illustrates the gravitation of missiles which lie free in the ventricle. The sketches made at autopsy tell the story, which therefore needs little context.

Case 83.—Rfm. H. S.

Admitted Aug. 15, 1917.—Comatose. Penetrating wound of mid-vertex, through helmet (rubbed missile); longitudinal-sinus syndrome. *X* rays (stereoscopic) show two widely separated foreign bodies near mid-plane of skull (*Fig.* 624). Death during preparation for operation, five hours after injury.

Autopsy (*Fig.* 625).—The two metal fragments (3 grm.) are evidently from one original piece, and show along one surface the rubbed and deformed margin produced by the helmet penetration (cf. *Fig.* 624).

The two examples in this group with a fatality from pneumonia are as follows. In the first, as in the case just recorded, two missiles, a primary and secondary, entered by the same wound.

Case 84.—Pte. S. H. R. (Serial No. 14).

Aug. 1, 1917.—Lying-out case with multiple wounds of leg, arm, and head. Condition bad. Penetrating wound, right temporo-frontal.

FIG. 626.—*Case* 84. Fragments of helmet and shell, both penetrating (natural size).

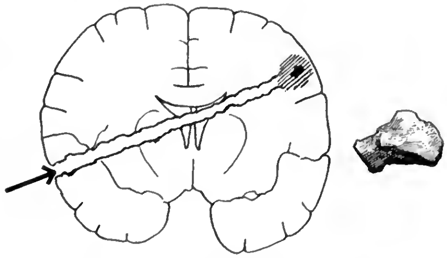


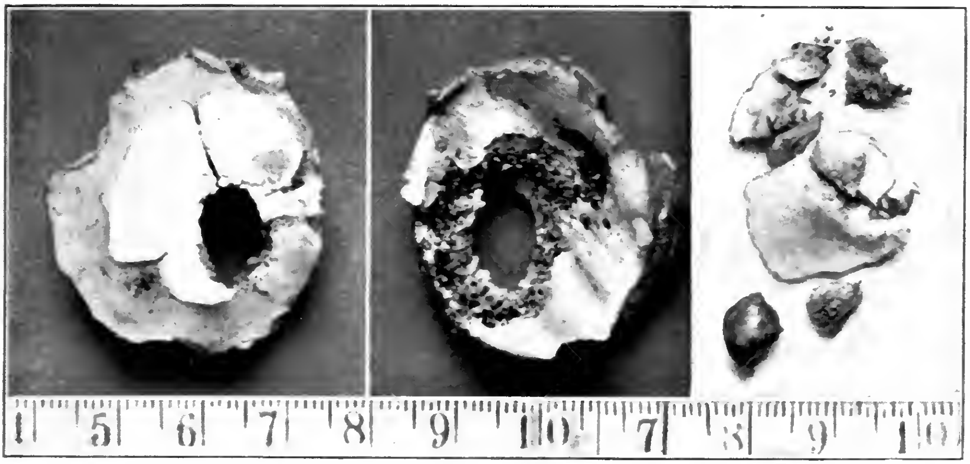
FIG. 627.—*Case* 84. Showing course of shell fragment.

Operation (24 hrs.).—Novocain. Temporal flap; closure. Pneumonia. Death on 4th day.

Autopsy.—Two tracks lead from the wound of entrance, one from a 1-grm. fragment of helmet (*Fig.* 626) into the right internal capsule, the other from a 0·6-grm. bit of shell through ventricle into opposite parietal lobe (*Fig.* 627). At end of each track is disorganized brain, but no abscess. No meningitis.

The second of these pneumonia cases is of interest from the fact that, with a mid-line penetration, the bone fragments were showered on one side, while the foreign body entered the other side of the falx.

Case 85.—Pte. C. G. (Serial No. 199). **Mid-line fronto-parietal penetration, traversing ventricle; missile retained; death from pneumonia 10th day.**



FIGS. 628, 629, 630.—*Case* 85. Trepanation block from directly over sinus; bone fragments and small missile with rubbed surface.

Oct. 22, 1917.—Admitted without history: unconscious: breathing badly. Resuscitation ward 6 hours. Mid-line parieto-frontal penetrating wound. X rays show missile in right occipital base. Neurological examination unsatisfactory.

FIG. 631.—*Case* 85. Showing tripod incisions; wound well healed to central point, sixth day.

Operation (6 hrs.) — Tripod incisions, exposing small penetrating wound, with elevated plates of outer table as in a wound of exit (*Fig.* 628). Trepanation *en bloc*, exposing intact sinus bridging a tear in the dura on each side. Through opening on left is a 5-cm. track with bone fragments: on the right a track filled with clot and pulped brain leads to depth through ventricle, which was completely emptied in the process of suction: no attempt made to recover missile. Dichloramine-T. Small catheter left in track; closure to central point (cf. *Fig.* 631).

Oct. 23.—Consciousness regained. Lumbar puncture: 20 c.c. bloody fluid (culture sterile). Purulent bronchitis, with excessive secretion. Catheter withdrawn on 4th day; wound intact; primary healing (*Fig.* 631). Neurological condition excellent, but continuance of pulmonary symptoms with fever. Death on 10th day.

Autopsy.—Bronchopneumonia. Track in right hemisphere leads through ventricle to base of occipital lobe, where is a foreign body in a small encapsulated abscess. No meningitis: no ventriculitis.

In the remaining seven cases death was in all certainty due to a meningeal or ventricular infection. The opinion has been expressed that small foreign bodies are well tolerated and should be left to work out their own salvation, and the investigation of late cases by Tuffier and by Holmes has been interpreted as an indication that these cases do well. It is true that, barring an occasional secondary abscess, they do well if they pass by the stage of early septic complication. Unfortunately, studies based on late results do not take into account the large percentage of cases which have succumbed early; and in fact these early septic complications are so frequent, that one may with all conservatism follow the rule 'always remove a foreign body when possible, unless the act of removal is likely to increase the damage already made by the penetration.'

Fig. 632.—Metal fragments from *Case* 86.

In many instances infection had become established from long lying out, as the first of the following cases indicates.

Case 86.—Sgt. E. R. (Serial No. 29).

Aug. 3, 1917.—Lying out 72 hours. Penetrating wound of frontal by three fragments (*Fig.* 632) of driving band of shell. Probably without helmet.

Operation.—Pulped lobe, with clot in ventricle. Two metal fragments extracted by magnet. Closure. Death in 24 hours.

Autopsy.—Early meningitis and ventriculitis. Fragments of bone in ventricle, and third piece of metal beyond it.

Case 87.—Sgt. R. K. (Serial No. 85).

Aug. 31, 1917.—Multiple wounds. Penetrating wound under helmet: left orbito-temporal. Irrational. Missile in opposite hemisphere. Flap operation; toilette of track; bloody cerebrospinal fluid (culture: staphylococci); gutta-percha drain. Urotropin. Sept. 2.—Lumbar puncture: 20 c.c. bloody fluid (culture sterile). Purulent bronchitis. Sept. 3.—Perfect

Fig. 633.—*Case* 87. Showing position of entrance wound with drain and flap incision, fourth day.

healing of external wound (*Fig.* 633). Continued cough. Better for following two days, then sudden rise in temperature, and death on 8th day, with evident pneumonia and meningitis.

Autopsy.—Track runs downward across brain, through falx and ventricles, to small 0·9-grm. fragment in centre of abscess (*Fig.* 634). Track infected; ventriculitis; meningitis; consolidation of entire right lung.

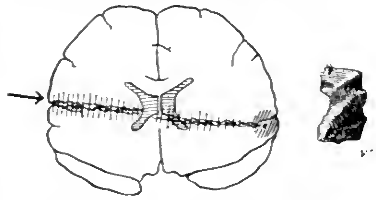


Fig. 634.—*Case* 87. Showing track and missile (natural size).

Case 88.—Sec.-Lieut. J. H. (Serial No. 119).

Sept. 20, 1917.—Minute penetrating wound in auriculo-temporal region, with chain of five small metal fragments. Aphasia; contralateral paralyses. Careful operation, with usual treatment of track; missiles not secured. No improvement in condition; fever. Sept. 22.—Lumbar puncture: bloody fluid under tension (cultures sterile). Death on 4th day.

Autopsy.—Marked comminution of petrous bone, with meningeal infection. Temporal lobe much disorganized, with track containing bone fragments; deepest missile leads into left ventricle, which is full of seropurulent fluid.

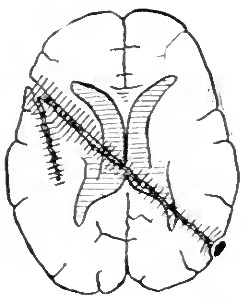


Fig. 635.—*Case* 89. Showing track and positions of two fragments.

Case 89.—Rfm. H. H. A. (Serial No. 123).

Sept. 20, 1917.—No history obtainable; probably lying-out case. Irrational; restless; irritable; critical condition. Penetrating wound of left temporal; brain extruding. Two missiles shown by *x* rays, one in left temporal, the other in right occipital lobe. Operation, requiring general anæsthetic. Usual track treatment by suction. Dichloramine-T. Missiles not secured. Death in 24 hours.

Autopsy.—Septic track through ventricle and brain to outer surface of opposite occipital lobe; missile subdural (fragment lost). Extensive encephalitis of left brain, with secondary missile (*Fig.* 635).

Case 90.—Pte. W. D. N. (Serial No. 131).

Sept. 22, 1917.—Deep stupor. Pulse 98. Two wounds, right parieto-temporal; one penetrating; brain extruding. No *x*-ray examination.

Operation.—Evacuation of clots, disorganized lobe, and bloody fluid. Continued bleeding from depth checked with difficulty. Incomplete closure. No return of consciousness. Death on 5th day.

Autopsy.—Widespread infection. Track leads across brain through ventricles, which are distended with blood-clot. Small 0·8-grm. bit of shell lies in abscess cavity under opposite meninges. Blood-clot in all cerebrospinal spaces (*Fig.* 636).

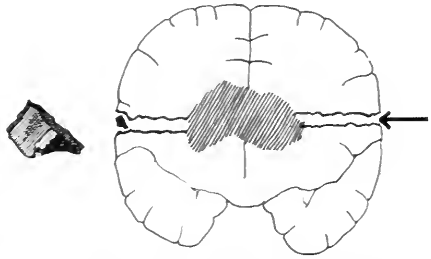


Fig. 636.—*Case* 90. Showing track through ventricle, and missile (natural size).

Case 91.—Cpl. R. J. H. (Serial No. 212).

Oct. 27, 1917.—Wounded 24 hours ago. Dull and disoriented. Small penetrating wound of left occiput. Brain extruding. *X* rays show small missile in parieto-frontal region, mid-line (*Fig.* 637). Right homonymous hemianopsia. Papillœdema.

Operation.—Usual procedure: trepanation *en bloc*: evacuation of clots, pulped brain, and cerebrospinal fluid; suction treatment of track to depth of 15 cm.; no bone fragments secured: direct drainage.

Oct. 29.—Headache. Lumbar puncture: yellow fluid, sterile on culture. Oct. 31.—Lumbar fluid shows streptococci. Death without usual high temperature.

Autopsy.—Track of small 0·5-grm. shell fragment (*Fig.* 637) passes from tip of occipital lobe through left ventricle and falx to right frontal lobe. Ventricle infected ; basilar meningitis.

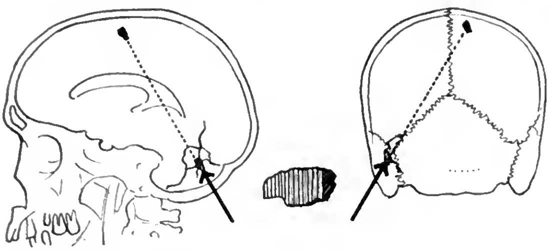


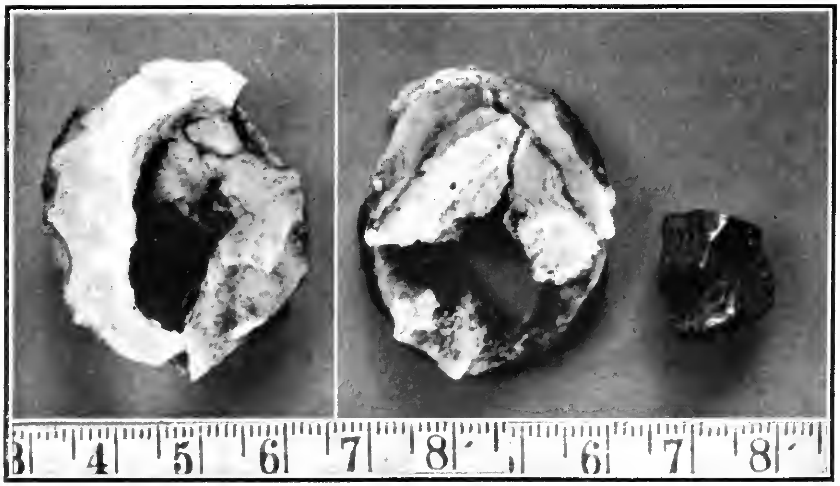
FIG. 637.—*Case* 91. From *x*-ray picture, showing position of missile (natural size).

The last of these cases may be given in a little more detail, for it shows how long a patient may hold out with a penetrated and infected ventricle.

Case 92.—Pte. E. H. (Serial No. 117). **Double cranial injury, from a split projectile: one fragment from fronto-parietal penetration free in the ventricle; the other lodged in parieto-occipital vault, with depressed fracture.**

Admission, Oct. 9, 1917, 4 p.m.—Wounded at 11.30 a.m. Wearing helmet. Temporarily unconscious ; recovered and walked in ; headache ; vomited once. General condition good ; conscious ; pulse 70 ; normal mentality.

Wounds.—(1) Lacerated, gutter type, right parieto-occipital ; (2) Lacerated, penetrating type, right parieto-frontal ; (3) Left scapular injury. *X* rays show



FIGS. 638, 639—*Case* 92. Block from posterior lesion, with lodged and burnished missile (*Group III* type).

posterior depressed fracture with superficial missile ; anterior fracture with indriven bone and missile.

Neurological Findings.—Practically nil. Deep reflexes over active, but equal.

Operation, 10 p.m. (11 hours).—Novocain.

Anterior wound : Tripod incision (cf. *Fig.* 640) ; trepanation *en bloc* : all fragments of inner table missing. Bleeding arachnoid artery caught with silver clips. Track leading across hemisphere to falx. Pulped brain and several bone fragments removed in process of usual toilette. Escape of bloody cerebrospinal fluid, with complete lowering of tension. Attempt at magnet extraction of missile unsuccessful. Dichloramine-T. Closure of dura and scalp.

Posterior wound: Tripod incision. Depressed fracture from an oblique blow, with lodged 8·3-grm. shell fragment (*Figs.* 638, 639) evidencing helmet penetration. Trepanation *en bloc*. Dura found punctured. Evacuation of disorganized brain. Closure; no drain.

Oct. 12.—Troublesome bronchitis. Temperature remains elevated. Extensive herpes labialis. Stiffness of neck. Lumbar puncture, with 20 c.c. yellow fluid (sterile on culture). The scalp incisions in good condition (*Fig.* 640). Oct. 14.—Mentality remains unimpaired; no neurological symptoms, but evidently some intracranial infection. Puncture repeated: 30 c.c. straw-coloured fluid (culture sterile). Oct. 16.—Continued high temperature (*Fig.* 641). No discomfort but from stiffness of neck.

FIG. 640. *Case* 92. Scalp wounds on third day.

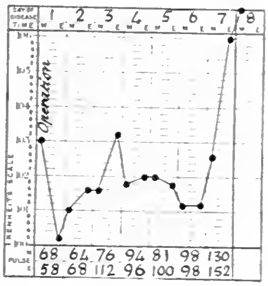


FIG. 641.—Temperature chart of *Case* 92.

Condition of external wounds perfect (*Fig.* 642). Oct. 17.—Death, with temperature of 106·5°.

Autopsy.—No evidence of meningeal infection.

Contusion of hemisphere under the posterior wound, without infection: also of fronto-parietal track, which leads across hemisphere and penetrates falx. The left ventricle is distended with pyoserous bloody fluid, with 3-grm. shell fragment lying free in posterior horn; it shows evidence of having perforated the helmet. The right ventricle is without evidence of infection. The foramen of Monro appears to be sealed (*Fig.* 643). The two missiles fit together, and are evidently from the

FIG. 642.—*Case* 92. Scalp wounds on seventh day.

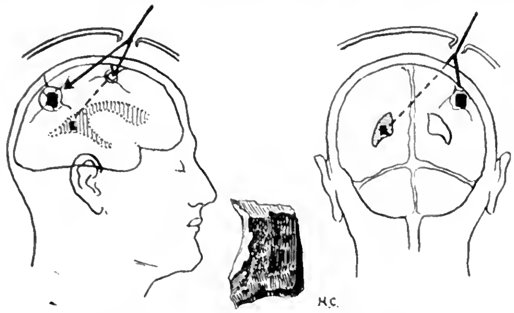


FIG. 643.—*Case* 92. Diagrams to show course of split projectile from site of helmet penetration.

same original piece, and were probably separated, as in *Case* 63, during passage through helmet.

This case, like others in the series, shows how little evidence of what may be taking place in the track within the brain is given by the appearance and condition of the external wound.

Group VII.—CRANIO-CEREBRO-FACIAL INJURIES.

The sixteen cases comprising this small group are put in a separate category with some misgivings. Subsequent studies of a larger series may make it seem unnecessary to separate them from the preceding or following groups in which they might be made to fall, or may suggest for them some still better disposition. They represent injuries, usually of a severe nature, in which, in addition to a wound exposing the brain, either the ethmoid cells and nasal sinuses have been opened, often with an associated injury of the orbit—a *cranio-cerebro-nasal type*; or the ear and petrous bone have been involved—a *cranio-cerebro-aural* type. In both types there is an added risk of secondary meningeal infection over and above that entailed by the original implantation of infective material directly in the wound.

Admittedly it is not always possible to sharply demarcate these cases. Some of them might well be included with the perforating wounds in the following section, and, on the other hand, examples of serious injuries to the petrous bone with dural penetration and fatal meningitis have been included in earlier sections (e.g., *Case* 88 in *Group VI*). However, in the long run, the cases are of a more immediately serious nature, and are associated with wounds which pass from face to cranium or the reverse. Some, particularly those involving the orbito-frontal region, are of a more or less bursting character, with marked elevation of large bone fragments, as will be seen.

Included in this group are 8 orbito-frontal cases, with 3 recoveries; and 7 auro-temporal cases, with 1 recovery. The mortality, therefore, was 73·3 per cent among this small number. In several of them, recorded as operated cases and therefore included in the series, the procedure consisted of little more than the mere cleaning up of the external wound and the instituting of some form of irrigation treatment.

A.—ORBITO-FRONTAL TYPE OF CRANIO-CEREBRAL INJURIES.

The three recoveries were as follows. The first of the cases is one of comparatively mild type.

Case 93.—Rfm. E. L. (Serial No. 127). **Fronto-nasal penetration, with injury of longitudinal sinus and indriven bone fragments. Operation. Recovery.**

Admitted Sept 21, 1917, 5.40 p.m.—No history obtainable, owing to mental state. Resuscitation ward over night.

Condition, Sept. 22, 9 a.m.—Restless; unbalanced mentality; pulse 66; body warm. (Almost stone deaf from childhood.)

Wound.—Lacerated mid-line gutter wound of scalp 5 cm. long, extending downward to glabella; slightly to left. *X* rays show fracture of frontal, with bone fragments indriven; small projectile imbedded in ethmoid on level of nasion.

Neurological Findings.—Tossing; mumbling; responses unintelligible. Reflexes hyperactive throughout. Examination otherwise negative.

Operation, 9 a.m.—Novocain. Excision of scalp wound, exposing perforation in bone just above frontal eminences. Trepanation *en bloc*, with removal of upper part of sinuses (*Figs.* 644–646). Extruded brain, filling sinuses. Dura found lacerated to right of mid-line; bleeding from longitudinal sinus easily checked by silver clip. On cleaning brain and clots from base of frontal sinuses, a fracture was

FIGS. 644, 645, 646.—*Case* 93. Trepanation block, entering frontal sinuses: from three aspects, with missile.

disclosed entering ethmoid cells, with lodgement of a small 1·6-grm. projectile (*Fig.* 646): surface burnished from helmet. Right frontal lobe underlying dural laceration considerably pulped. Suction procedure, with recovery of fragments of bone at 3 cm. depth. Dichloramine-T in sinuses. Partial closure, with rubber catheter drain.

Post-operative Course.—Infection of scalp wound, which was opened at upper end and drained. A considerable rise in temperature on the 4th day, and again on the 17th day to 104°. Otherwise no untoward symptoms. Abundant discharge from sinuses: continued use of dichloramine-T, with drain until Sept. 21, when drains were removed and there was no further discharge. No apparent mental symptoms. Evacuated Sept. 23 (31 days).

Subsequent Report.—Dec. 12, 1917 (letter from father).—At King George Hospital since Nov. 7. Wound healed; up and about: feels well.*

The next case is remarkable for the large projectile, and for the recovery after a badly infected and complicated wound.

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* Since these notes, the boy's father reports that he had been very well, but after attending a concert he had a series of fits, and died on Jan. 4 in status epilepticus. An autopsy was held, and showed no abnormalities aside from the healed wound and a tuberculous spleen. This was the first convulsion he had had.

Case 94.—Pte. P. T. (Serial No. 129). **Fronto-orbital penetration by a 47-grm. projectile. Gas infection. Operation. Recovery.**

Admitted Sept. 21, 1917, 6.45 p.m.—Transferred for operation Sept. 22, at 2.30 p.m., *circa* 30 hours after injury.

General Condition.—Semi-conscious, but can be roused. History vague: thinks he was wounded going over parapet two days ago. Helmet perforated (burnished projectile). Body warm; pulse 80; temperature 100°. No irritability or restlessness.

Wound.—Circular; left frontal eminence; occluded by extruding brain with a gassy odour. Protrusion and ecchymosis of left eye. *X* rays show large foreign body partly imbedded in orbit (*Figs.* 647, 648).

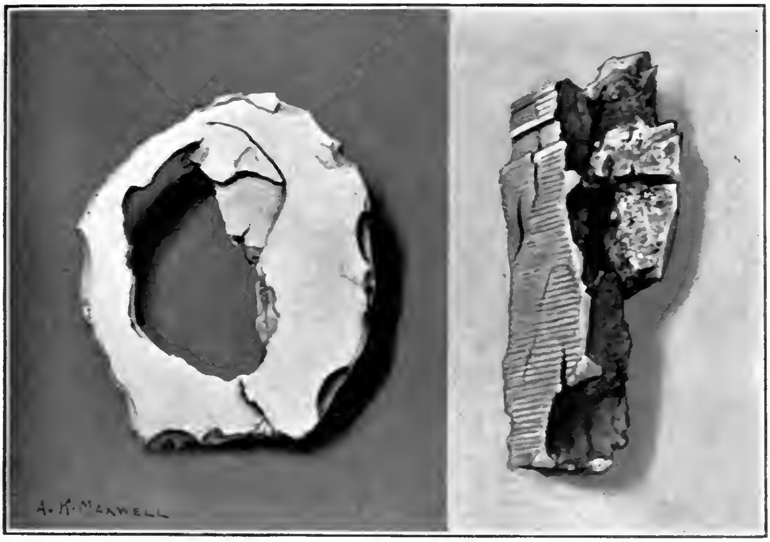
FIG. 647.—*Case* 94. Lateral *x*-ray photograph.

FIG. 648. *Case* 94. Frontal *x*-ray photograph.

Neurological Findings.—No mental disturbance apparent. Marked exophthalmos of left eye, with blindness and immobility of globe; pupil dilated; ptosis of lid. Increased deep reflexes. Patient right-handed.

Operation, 2.30 p.m. (30 hours).—Novocain. Tripod incision: trepanation *en bloc* (*Fig.* 649). Complete absence of fragments of inner table: radiating lines of fracture pass down across the frontal bone. Large opening in dura occluded by stinking fungus, which was blunt-spooned away. Track leads at 3-cm. depth to upper end of missile, which was wedged too securely for withdrawal. Fragment loosened by magnet and withdrawn; extremely foul odour; weight 47 grm.; corners of the lower end burnished by passage through helmet (*Fig.* 650). Track cleansed by suction method, including the entire pulped tip of lobe; several bone fragments removed. Opening the size of a sixpence through broken roof of orbit; orbital fat crushed and infected. Large cavity filled with cotton pledgets dampened with dichloramine-T. Partial closure of incisions: direct drainage. Cultures: *B. perfringens* and staphylococci; no streptococci.

Post-operative Course.—For two or three days the wound looked very badly, and for a week retained its foul gassy odour. The fresh incision became infected, and had to be opened and drained (*B. perfringens*). The temperature remained low



FIGS. 649, 650.—*Case* 94. Trephine block and missile (natural size), showing rubbed edges from helmet penetration.

from the outset (*Fig.* 651). The fungus became covered with a slough, and great difficulty was experienced in securing proper drainage from the infected orbit, as the fungus tended to occlude the wound. Every second day for ten days a lumbar puncture was necessary in order to collapse the fungus sufficiently to expose the

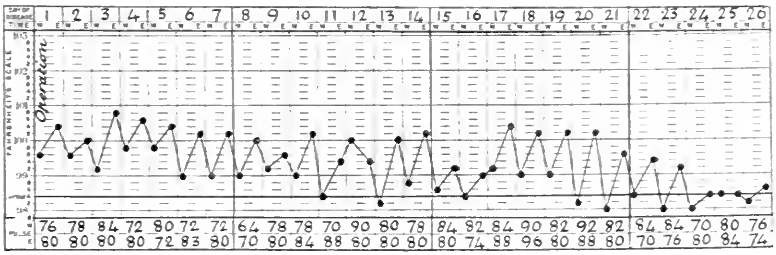


FIG. 651.—Temperature chart of *Case* 94.

opening into the orbit (*Fig.* 652) and permit the placement of proper drainage. The fluid was always clear and sterile. Dichloramine-T was used throughout; the sloughs finally separated, and by the 20th day the fungus began to subside. Finally the wound was grafted. Patient was evacuated in excellent condition on the 45th day, after being up for ten days.

Subsequent Report.—Nov. 14, No. 16 General Hospital.—"No positive clinical evidence of damage to frontal lobe . . . left blindness with optic atrophy; ptosis; paralysis of the superior rectus muscle . . . no other neurological abnormalities Evacuated to England." No subsequent report.

This example of gas infection speaks well for the open treatment of such conditions with dichloramine-T. It is possible that some of the difficulties of after-treatment might have been overcome had an immediate enucleation of the eye been performed, with direct drainage through the roof of the orbit.

FIG. 652.—*Case* 94. Showing collapse of fungus after lumbar puncture, giving access to orbit.

In the following case the orbito-frontal injury was received in the other direction—through orbit to frontal lobe.

Case 95.—Pte. S. B. (Serial No. 139). **Orbito-fronto-cerebral penetration by 53·2-grm. shell fragment. Recovery.**

Admission Sept. 26, 1917, 4.30 p.m.—Injured 9 hours before. Missile passed under helmet; knocked down; no loss of consciousness.

General Condition.—Good. Patient conscious and rational. Pulse 80.

Wound.—Irregular lacerated; in region of left eyebrow; lids swollen and closed. Narrow bridge of upper lid remains intact (cf. *Fig.* 656). *X*-ray report: "Large metal fragment in orbit" (*Figs.* 653, 654).

FIG. 653.—*Case* 95. Frontal radiogram.

FIG. 654. *Case* 95. Lateral radiogram.

Neurological Findings.—Negative.

Operation. 7 p.m. (12 hours).—Novocain. Slight enlargement of wound, without

excision. Extraction of large 53·2-grm. missile (*Fig.* 655), which had passed through supraorbital ridge and become securely wedged deep in orbit (chloroform necessitated for its extraction). Roof of orbit had been torn away, widely exposing base of frontal lobe, from site of supraorbital notch through frontal sinuses and inwards to the anterior ethmoid region. Enucleation of collapsed eyeball. Dichloramine-T ; full drainage.

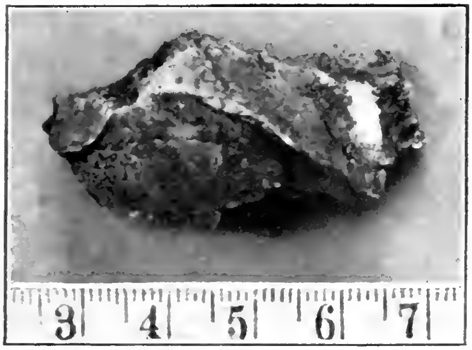


FIG. 655.—Projectile from *Case* 95 (natural size).

Post-operative Course.—Daily dressings of wound (*Fig.* 656). Recovery uncomplicated, except for an oculomotor paralysis of the right eye which appeared about the 10th day. Highest temperature 100°. Protruding brain well healed over. Evacuated Oct. 23.

Subsequent Reports.—No. 12 General Hospital.—Had received, Sept. 26, 1000 units antitetanic serum. No second injection. Developed tetanus, Oct. 30. Recovered. Evacuated to England, wound healed, good condition, Nov. 8. Feb. 21, 1918 (by letter from Medical Officer, Bath War Hospital).—After discharge of bone fragments, left eye has practically healed ; normal movements regained in right eye ; good condition.

FIG. 656.—*Case* 95 on tenth day.

The Fatal Cases.—The other five cases which fall in this cranio-cerebro-nasal category all succumbed ; most of them were hopeless from the outset. The histories follow. In the first, a large unsuspected abscess formed in the relatively undamaged hemisphere.

Case 96.—Sgt. C. C. (Serial No. 50). **Multiple wounds. Large shell fragment penetrating frontal region, with elevation of area of sinuses. Cerebral abscess. Death 4th day.**

Admission, Aug. 14, 1917, 6.15 p.m.—Insists that he was wounded two days before, and that he made his way back alone to aid station. Has had vomiting and headache.

General Condition.—No apparent shock ; pulse 80 ; replies with intelligence to questions.

Wounds.—(1) Large circular ragged penetrating wound of entrance at angular process, right frontal ; brain and clots extruding ; some fresh bleeding ; ecchymosis of eyes ; palpable loose fragments of frontal area ; (2) Gutter wound of scalp above left ear ; (3) Penetrating wound of chest through right shoulder ; (4) Penetrating wound of arm ; (5) Penetrating wound of right cheek. *X*-ray picture (*Fig.* 657) of head shows large projectile in mid-frontal region ; extensive fracture, with elevation of frontal area.

Neurological Findings.—Easily roused, and responds readily, though somewhat hazily. No disorientation or other mental loss observable.

FIG. 657.—*Case* 96. Radiogram (one-half natural size).

Operation, 11 p.m. (? 48 hours).—Novocain. Repair of extensive fracture; entire upper portion of frontal sinuses found elevated and completely detached; area removed, with large 50-grm. missile (*Fig.* 658). Radiating lines of fracture run backward, with many loose plates of bone: left in place. Ragged tear in dura over right frontal lobe; much disorganized brain cleaned away. Wound left open. Carrel-Dakin treatment.

Aug. 17.—Very good condition for first three days. Daily dressings. Cultures from wound surface showed *B. perfringens* in abundance, but there was no tendency to fungate. Temperature 99° to-day; pulse 110. Aug. 18.—Some headache. Lumbar puncture: fluid clear, and straw-coloured (culture negative). No clinical evidence of meningitis. Later in the day became unconscious; temperature rose to 105°. Condition unexplained. Death.

Autopsy.—On removing brain, no evidence of meningitis. Surface of the damaged right frontal lobe covered by superficial slough, at back of which the hemisphere appears normal. The left frontal lobe, however, is occupied by a huge, partly encapsulated abscess, extending back almost to the Rolandic area, and leaving only a thin shell of brain. This abscess communicated with wound through a small punctured opening in the dura at the anterior tip of the lobe; puncture not observed at the operation.

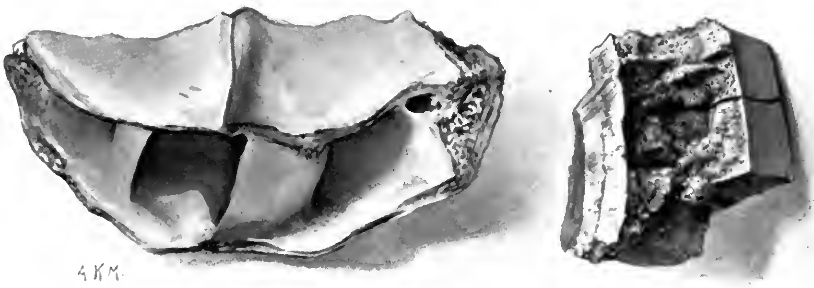


FIG. 658.—*Case* 96. Showing detached block of supra-orbital region, with 50-grm. projectile (natural size).

The following is an example of an unpromising condition for which, after a period of procrastination, one may at times be encouraged to intervene, despite the seemingly hopeless outlook.

Case 97.—L.-Cpl. T. K. (Serial No. 79). **Severe orbito-frontal perforating wound from rifle ball. Gas encephalitis. Death.**

Admission, Aug. 27, 1917, 7.10 p.m.—History unreliable: says he was wounded three days ago and has been lying out. Case regarded as unoperable: sent to resuscitation ward.

General Condition, Aug. 28, 3 p.m.—Good; conscious; warm; pulse 80.

Wounds.—Small entrance wound over left malar eminence. Eye completely pulped. Large stellate wound of exit over right supra-orbital area (*Fig*. 659), with extruding brain and bone. *X* rays show fracture through sinuses, with elevation of fragments; two small projectiles in antrum.

Neurological Findings.—Memory very defective. Orientation much impaired. Listless and vague in answers; irritable. No paralyses.

Fig. 659.—*Case* 97. Showing wound before operation.

Operation, 3 p.m. (*circa* 48 hours).—Novocain. Repair of ragged frontal wound, with removal of large pieces of dislodged sinuses and a small bit of jacket of rifle ball. Very large opening in dura 3 cm. in diameter, from which bleeding and lacerated brain extrudes. Track leads through ethmoid region into orbit. Eyeball, which had been traversed, enucleated. No attempt at closure. Carrel-Dakin treatment.

Aug. 30.—Complete loss of inhibitory faculties: singing; restless; reaching for imaginary objects; impossible to keep him in bed or to keep an intact dressing. Death Aug. 31, with temperature of 103°.

Autopsy.—Both frontal lobes pulped and disintegrated, and entire anterior half of right hemisphere softened and hæmorrhagic. Odour of gas infection. Linear fractures pass from large anterior defect back as far as parietal eminences.

The following was a similar and equally desperate case, with, however, a temporary promise of recovery.

Case 98.—Sig. G. F. (Serial No. 114). **Orbito-frontal perforating wound with large cerebral hernia. Death 6th day.**

Admission, Sept. 20, 1917, 11.30 a.m. — No reliable history was obtainable. Irrational; disoriented for time and place; quiet. Condition good. Pulse 64.

Wounds.—Multiple. Small wound of entrance in left temporal region (*Fig*. 660), with exit through orbito-frontal area, destroying eye; large cerebral herniation.

Additional wounds of right scalp and right shoulder. *X* rays show extensive fissures of frontal and parietal bones.

Neurological Findings.—Aside from disordered mentality, no positive findings.

Operation, 2 p.m. (*circa* 6 hours ?).—Chloroform. Enucleation of collapsed eyeball; removal of free fragments of bone from orbit: frontal and ethmoid sinuses widely opened. Wound Carrelized, tubes being led in through wound of entrance.

Fig. 660.—*Case* 98. Showing wound entrance and exit. before operation.

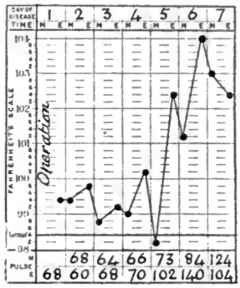


Fig. 661.—Temperature chart of *Case* 98.

Post-operative Course.—Condition remained very promising for three days, despite the continued extrusion of large amounts of cerebral substance into the orbital cavity. A marked rise in temperature occurred on Sept. 24 (*Fig.* 661), and death the following day.

Autopsy.—Extensive basilar meningitis, apparently due to fissured cribriform plate causing tear in overlying dura. No evident cerebral œdema or encephalitis.

The next case exemplifies further the chief hazards of these low frontal injuries—namely, a fracture of the ethmoid, with a meningo-nasal communication.

Case 99.—Pte. D. H. (Serial No. 90). **Fronto-orbital gutter wound; laceration of dura; fracture of ethmoid. Cerebrospinal rhinorrhœa. Pneumococcus meningitis.**

Admission, marked 'urgent,' Sept. 3, 1917.—Bleeding from wound; anæmia; irregular feeble pulse; profoundly unconscious; cold and wet. Immediate operation.

Wound.—Gutter type (*Fig.* 662), vertical, through fronto-orbito-temporal region; no brain extruding.

Operation.—Excision of scalp wound, with ligation of bleeding vessels. Gutter wound of frontal angle, with large indriven piece of bone widely lacerating dura; radiating lines of fracture. Malar bone entirely dislodged, with fractures of zygoma and external orbital plate. Partial closure; drainage.

Sept. 4.—Cerebrospinal rhinorrhœa; evident meningitis, probably pneumococcal. Lumbar puncture, with only 3 c.c. fluid obtained (culture: pneumococcus). Death in 48 hours.

Autopsy.—Several lines of fracture radiate from defect, and cross cribriform plate to opposite side. Extensive basilar meningitis, spreading chiefly over right hemisphere.

The remaining case in this group properly belongs among the perforating cases, where one very much like it (*Case* 109) will be found. The wound traversed the orbito-nasal region, much as in the attempted-suicide type of wound, with division of the optic nerves. The case is placed here, however, as the ultimate fatality was due to an ascending infection from the nasal cavity. Nothing more than slight enlargement of the wound of entrance, with drainage, was possible; and such a case might with some justice be omitted in quoting statistics of an operative series, were it proper to eliminate any case whatsoever.

FIG. 662.—*Case* 99. Showing wound before operation.

Case 100.—Rfm. J. T. (Serial No. 132). **Perforating temporo-orbital wound. Fracture of ethmoid. Temporizing operation. Death 10th day.**

Sept. 20, 1917.—An 8-grm. shell fragment (*Fig.* 663) passed from the right temporal region, just grazing the pinna, to the left orbit, where it lodged in the upper lid. The patient, profoundly unconscious, was regarded as moribund, and no operative measures were undertaken till the third day, when the wound of entrance was repaired, the track sucked clear of clot and disorganized brain, and the missile removed from the left eye. Contrary to all expectations, he survived until the 10th day, and succumbed to a pneumococcus meningitis.

Autopsy. — The track led across the base of the right temporal lobe, and passed through the sphenoid and ethmoid into the left orbit; both optic nerves were divided (*Fig.* 664). Extensive basilar meningitis.

FIG. 663.—*Case* 100. 8-grm. unrubbed shell fragment.

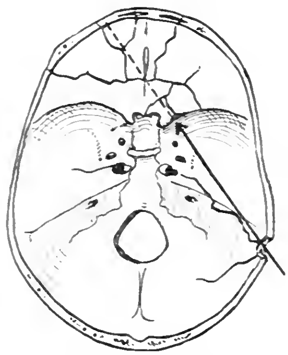


FIG. 664.—*Case* 100. Showing course of projectile.

It is possible that Dakin's disclosure of the antiseptic value of dichloramine-T when sprayed on the nasal mucous membrane, may make this an invaluable routine procedure in all basal fractures involving the cribriform plate.

B.—Auro-temporal Type of Cranio-cerebral Injuries.

In this type the percentage of fatalities was still higher, there being only one recovery. As in the foregoing, where infection extended from the nose, so here the chief danger lies in the extension of a septic process through a lacerated dura from the middle ear when the petrous bone has been seriously injured.

Case 101.—Pte. C. J. L. (Serial No. 118). **Multiple wounds Severe gutter wound of right auro-temporal region. Recovery.**

Admission, Sept. 20, 1917, 6 p.m.—Injured four hours earlier by high-explosive shell. Temporary unconsciousness. Severe headache. Considerable shock.

Wounds.—Multiple small wounds of right face and neck, with severe gutter fracture across lower temporal and zygomatic regions (*Fig.* 665); muscle lacerated; brain extruding. Lacerated wound of left arm. Compound fracture of left forearm. *X* rays show no missile.

Fig. 665.—*Case* 101. Showing wound after preparation for operation.

Neurological Findings.—Marked nystagmus; apparent weakness (cerebellar ?) of left side. Deep reflexes active, but equal. No mental disturbance.

Operation, 12 midnight (10 hrs.) Chloroform. Rapid repair of all wounds. Mere edges of temporal wound refreshed, with removal of fragments of squamous and petrous bones. Bleeding from extensive fungus controlled. No attempt at closure. Dichloramine-T. Gutta-percha dressing.

Post-operative Course.—Wound remained clean; highest temperature 101°; considerable discharge of sero-purulent fluid (cerebrospinal ?) from ear for ten days. The necrotic surface of the fungating area finally became covered by the folding down of a flap of the torn temporal muscle. Discharged on 21st day: wound nearly healed.

Subsequent Report.—Oct. 21, No. 7 General Hospital.—No neurological symptoms; small granulating area; evacuated to England.

The Fatal Cases.—The following two cases are very similar to the foregoing, but with a less happy outcome.

Case 102.—Pte. W. S. (Serial No. 81).

Aug. 28, 1917.—Severe multiple wounds—head, forearm, thigh. Lying out 24 hours: poor condition. Lacerated wound, major type, across left temporo-aural region, completely dividing pinna and fracturing temporal and petrous bones. Makeshift repair under chloroform. Cheyne-Stokes breathing and final cessation

of respiration followed operation: breathing resumed after prolonged artificial respiration. Death on 3rd day: symptoms of meningitis.

Autopsy.—Deeper fragments of petrous bone penetrating dura: temporal lobe greatly contused; extensive leptomeningitis spreading from this area.

Case 103.—Pte. A. M. (Serial No. 21).

Aug. 2, 1917.—Rifle ball passing under helmet. Wound *en séton*, left temporal region; entry near external angular process; exit above mastoid. Considerable shock. Aphasia. Very difficult bloody operation; fractures of squamous and petrous bones, with deeply indriven fragments; bleeding meningeal; extensive laceration of temporal lobe. Partial closure.

Fungus cerebri with secondary hæmorrhage on 6th day. Enormous fungus gradually cleaned up, and temperature was normal till 20th day: sudden meningeal symptoms. Death on Aug. 27 (26th day).

Autopsy.—Purulent meningitis: septic track containing bone fragments leading through temporal lobe (*Fig.* 666). Lateral ventricle drawn out into hernia and opened. Ventriculitis. Septic thrombosis of lateral sinus and jugular bulb.

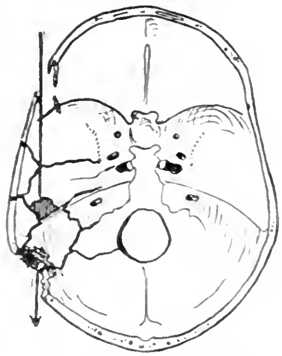


FIG. 666.—*Case* 103. Showing course of projectile.

The following three are examples of penetrating rather than gutter wounds of the region.

Case 104.—Dvr. J. E. J. (Serial No. 3).

July 25, 1917.—Wounded previous day. Admitted cold and pulseless, with double cranial wounds: (1) Supra-orbital; (2) Penetrating wound of right mastoid. Resuscitation therapy. July 26.—Signs of failing: Cheyne-Stokes respiration; choked disc of 2 D.

Operation.—Ether. Subtemporal decompression as last resort; right mastoid and petrous bones badly fractured, with embedded shell fragment, torn dura, cerebral extrusion, and sigmoid sinus thrombosis; wound left open.

Marked improvement for three days: bronchopneumonia; meningitis. Death at 6 p.m. July 30 (6th day).

Autopsy.—Extensive laceration of lower right occipital lobe containing indriven bone fragments; extensive disorganization of right cerebellar hemisphere. Mastoiditis; septic sinus thrombosis; meningitis of posterior fossa.

Case 105.—Pte. H. D. (Serial No. 155).

Sept. 28, 1917.—Lacerated wound over left mastoid, received previous day. Marked dizziness: nystagmus: some ataxia on right side. Operation showed depressed fracture of mastoid region, with injured sinus and punctured dura; wound left open. Early meningitis. Lumbar puncture (Gram-positive cocci in pairs). Death in 4 days.

Autopsy.—Mastoiditis: septic sinus thrombosis: purulent leptomeningitis: marked contusion of lower part of temporo-sphenoidal lobe.

Case 106.—Cpl. R. W. (Serial No. 34).

Aug. 3, 1917.—Penetrating wound through right external auditory meatus. Shock: resuscitation ward. Pressure symptoms: unconscious: pulse 112: respiration 44. Cheyne-Stokes; pupils dilated: right facial paralysis. *X* rays show missile in left cerebellum.

Operation, 3 p.m.—No anæsthetic. Flap procedure, with exposure both of temporo-occipital and right cerebellar regions: many loose fragments of petrous bone removed: internal ear opened; cerebellar dura tense; incised; lobe much lacerated: clots removed; missile not detected. Death at 8.30 p.m.

Autopsy.—Inferior temporal lobe and right cerebellum greatly pulped. Petrous bone almost entirely blown out; two large fragments had been driven with the

missile (*Fig.* 667) across the cerebellum just above the brachium pontis, and lay in the left cerebellar hemisphere (*Fig.* 668).

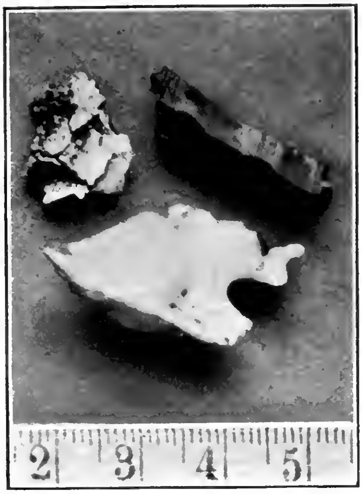


FIG. 667.—*Case* 106. Missile and loose fragments of petrous bone removed at operation.

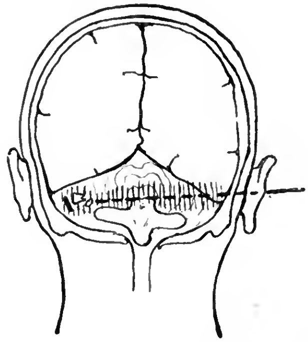


FIG. 668.—*Case* 106. Showing course and position of missile.

The last of these cases, though bizarre owing to the character of the secondary projectile, was typical of the group, in so far as the character of the fracture was concerned. The meningeal infection was in all probability from a direct implantation rather than due to an extension from an infected inner ear.

Case 107.—Pte. H. T. O. (Serial No. 82).

Aug. 28, 1917.—From resuscitation ward: history unobtainable. Condition bad; semi-conscious. Multiple wounds of right side of head, right elbow, right leg, all containing indriven foreign bodies. A cerebrospinal-fluid leak from deep gash over right zygoma. *X*-ray picture of head shows 13 missiles of varying character and size: one long hooked-shaped object embedded in petrous bone.

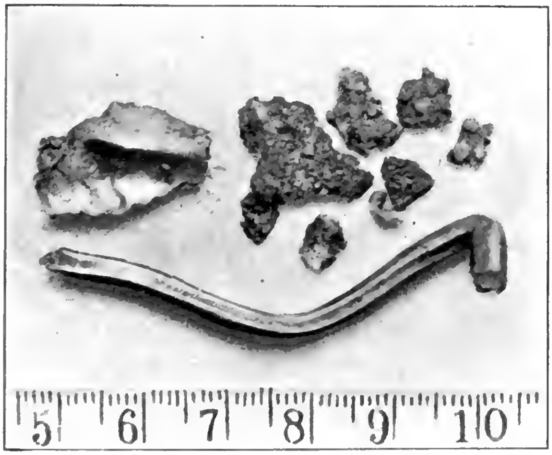


FIG. 669.—*Case* 107. Fragment of petrous bone and multiple foreign bodies.

Operation.—Chloroform. Excision of temporal wound; skull fractured by penetration of long brass object (part of equipment, *Fig.* 669) which has entered temporal lobe its full length; fluid escapes along this track; fragments of indriven squamous and petrous bones removed, exposing the entire inner ear; thorough drainage; repair of other wounds.

Aug. 30.—Cessation of fluid leak for 24 hours, with signs of meningitis. Ventricular punctures: 20 c.c. turbid fluid (culture: pneumococci). Aug. 31.—Lumbar puncture: turbid fluid (pneumococci). Sept. 1.—Exitus.

Autopsy.—Lines of fracture extend into petrous bone and orbital plate; temporal lobe pulped and hæmorrhagic; also right cerebellum; extensive basilar meningitis.

One recovery in seven cases, an 85·7 per cent mortality, can hardly represent the actual figures for this variety of cranio-cerebro-aural lesions. A trustworthy estimate cannot be based on figures so small. They serve, however, to point out the seriousness of injuries which involve an area that cannot be easily approached, and which harbour infections that can readily extend into adjacent torn meninges. Doubtless better methods of dealing with them can be evolved.

Group VIII.—WOUNDS TRAVERSING THE CRANIAL CHAMBER.

In its typical text-book form, as illustrated in the diagram (p. 563), few examples of cranial perforation occurred in the operative series. Victims of perforating wounds of the bipolar variety who survived to reach the casualty clearing station were usually moribund on admission, and later in the season, as the lines advanced and recovery of the wounded became still more delayed, few of them were seen.

Fig. 670.—*Case* 108. Wounds before operation.

As will have been observed, cases in which the missile actually traversed the cranial chamber, but stopped short of emergence, were recorded among the penetrating wounds in *Group V*. Cases, moreover, which with more reason might be regarded as true examples of perforating wounds, have been included with the cranio-cerebro-facial type of injuries in the preceding section.

Thus narrowed down, the present group contains only 5 cases, with but 1 recovery (mortality 80 per cent). The single recovery was an example of 'bow-string' perforation similar to that given in *Case* 103, though the level of injury was higher in the vault. The case follows.

Case 108.—Pte. C. B. (Serial No. 153). **Right temporo-parietal arc perforation. Operation. Recovery.**

Admission, Sept. 29, 1917, 5 a.m.—No history; semi-conscious; vomiting; shock. Resuscitation ward.

Wounds.—Entrance and exit, of seton character (*Fig.* 670); brain extruding. X-ray report: "Indriven bone fragments: no missile."

Neurological Findings.—Examination unsatisfactory, though evident weakness of left face, arm, and leg; tendency to conjugate deviation of head and eyes to right; deep reflexes brisk, equal, without clonus; no plantar response on left, normal on right.

Operation, 3 p.m. (*circa* 12 hours).—Novocain. Tripod incisions, with inclusion of scalp wounds. Severe fracture of temporo-parietal region, with broken fragments between wounds of entrance and exit. Temporal lobe greatly contused and hæmorrhagic, with bleeding afresh from torn Sylvian vessels on dislodging bone fragments; vessels secured with clips. Disorganized brain tissue sucked and irrigated out. Closure without drainage.

Fig. 671. *Case* 108. On first dressing.

Post-operative Course.—Rapid improvement in general condition. Left homonymous hemianopsia disclosed. Focal seizures of face and arm on 4th day. Continued tendency of head and eyes to right deviation. Perfect wound healing (*Figs.* 671, 672). Slow improvement in palsy of face and arm. Evacuated Sept. 9 (11th day).

Fig. 672. *Case* 108. On discharge

Subsequent Reports.—Oct. 10, No. 18 General Hospital.—General condition good. Evacuated to England. Nov. 5, No. 2 New Zealand General Hospital.—Slight occasional headaches. Paresis of left face and left half of tongue. Sluggish mentality. Boarded as unfit. No later report.

The Fatal Cases.

Most of these were subjected to very cursory procedures, which, however, necessitate their inclusion in an operative series. It is extraordinary how long may be the period of survival if the bulbar centres have escaped and pressure phenomena are not severe. One cannot abandon

these severe cases to their fate without some effort toward surgical cleanliness, if nothing else.

Case 109.—Pte. H. N. (Serial No. 28).

Aug. 1, 1917.—Unconscious; no history; vomiting; pulse 120. Perforating wound, presumably rifle ball; entrance right parieto-frontal, exit left supra-orbital region; bleeding brain extruding from each wound (*Fig.* 673).

Operation.—Temporizing repair of major wound of exit, with control of hæmorrhage; partial closure. Death in 6 hours. No autopsy.

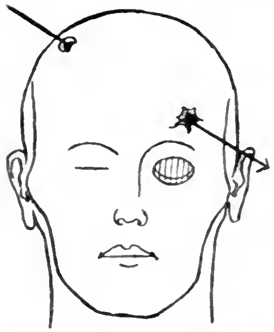


Fig. 673.—*Case* 109. Course of traversing missile.

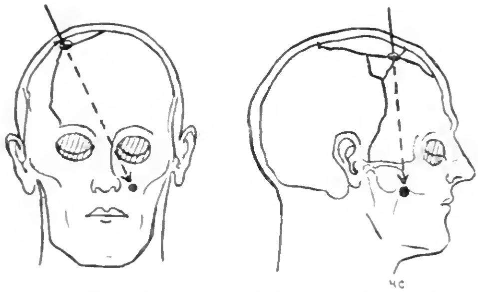


Fig. 674. *Case* 110. Course of traversing missile.

Case 110.—Pte. F. B. (Serial No. 133).

Sept. 20, 1917, 6 a.m.—Irrational; noisy; fighting; no history obtainable; good general condition; pulse 60. Wound of entrance, right fronto-parietal; brain extruding. Shrapnel ball in right maxilla. Compound fracture of left arm. Extreme proptosis both eyes; nasal bleeding. Morphia; temporizing dressings and Thomas splint. Sept. 22.—Same condition; marked escape of cerebral substance; suction treatment of track, with removal of large amount of disorganized brain and clots. Sept. 24.—Slight operative repair of entrance wound, with removal of bone fragments, and catheter drainage. Death on Sept. 25, 3 p.m.

Autopsy.—Right parieto-frontal entrance wound, with far-reaching meridional fissures (*Fig.* 674). Exit wound through greater wing of left sphenoid; track continues into maxilla, where shrapnel ball is lodged under mucous membrane of throat. Septic meningitis.

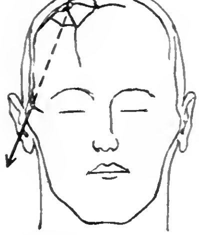


Fig. 675.—*Case* 111. Course of traversing missile.

The long-drawn-out course of some of these serious wounds, when left to pursue their own way, is shown by the following example.

Case 111.—Pte. W. I. R. (Serial No. 182½).

Oct. 11, 1917.—Admitted with history of lying out for four days. Conscious. Temperature 101·8°. Condition very poor. Multiple wounds: (1) Perforating in arc of right parieto-temporal region (*Fig.* 675), with brain extruding; (2) Perforating of right shoulder.

Operative repair of cranial wounds: badly infected gassy brain: temporal lobe completely disorganized (culture: *B. perfringens* and staphylococci): no attempt at closure. Subsequently large amounts of foul cerebral tissue escaped and large hernia formed. Survival for three days.

Autopsy.—Disorganization by encephalitis of almost entire right hemisphere; gassy odour.

In the following instance, as in the cases in *Group VI*, the ventricle was traversed by the missile in its course.

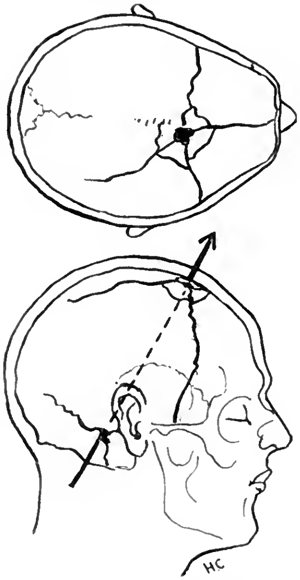


FIG. 676.—*Case* 112. Course of traversing projectile.

Case 112.—Pte. F. S. (Serial No. 188).

Oct. 12, 1917.—Semi-conscious; aphasic; no story obtainable. Good general condition. Wound of entrance, left mastoid; exit near mid-vertex (*Fig.* 676); brain extruding from both. Complete right hemiplegia.

Conservative operation under novocain, with catheter suction of disorganized tissue and clots from track, reducing tension. Dichloramine-T. Death on following day.

Autopsy.—Large extradural clot; widespread meridional fissures from wound of exit. Track of projectile passes directly through ventricle, which contains pyoserous fluid and indriven bone fragments.

Justice, in this brief section, has hardly been done to these traversing wounds. As the season progressed, the conditions of the terrain became such that few with wounds of this type survived to be brought back, and those who did had well-established infections. Under better conditions there should be a much higher degree of recoverability from perforating wounds than these few illustrations would indicate.

Group IX.—BURSTING FRACTURES WITH WIDESPREAD CEREBRAL CONTUSION.

In this, the last, group have been placed certain cases of major severity in which diffuse cranial fractures are associated with extensive and widespread contusions of the brain. They represent a type of injury which can be best relieved by a properly conducted cerebral decompression.

Massive fractures of the skull may occur, indeed often occur, without actual laceration of the scalp, and in fact there are certain varieties of crushed skull which have led to the assumption that some of these injuries may be due to the diffuse transmission of a blow from a heavy projectile through the well-fitting band of the helmet. Grave accidents, however, from being buried under heavy falling objects are so common in present-day warfare, that one must be cautious in attributing to a projectile itself a possible secondary effect of the explosion; and the majority of such patients are too profoundly unconscious on their admission to give any history, and usually have complete amnesia of the occurrence in the event of recovery.

Among the 10 cases in the series which have gravitated to this group, there were 5 fatalities (mortality 50 per cent). This fairly high percentage of recoveries does not really represent the grade of case which the group was intended to contain, for a number of surgically treated fractures, largely basilar in type (three), have come to be included for lack of a more suitable

group in which to put them. Other basilar fractures which recovered without operation or following a lumbar puncture are incorporated among the non-operative cases.

Many examples of extensive egg-shell injuries, with fissures which radiate from a local impact or penetration made by a missile, have been recorded in the preceding sections. Fractures of this kind, in which the indications for local investigation are clear, are of quite a different order from those here considered.

The following two cases exemplify the type of injury under discussion.

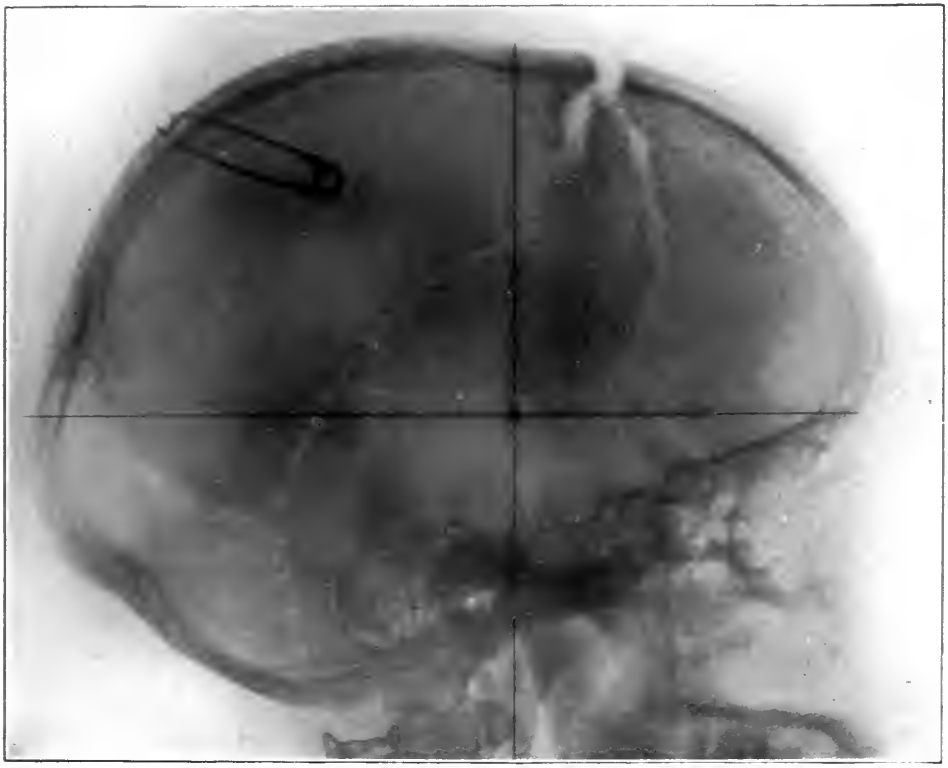


FIG. 677.—*Case* 113. Radiogram of bursting fracture.

Case 113.—Pte. W. W. (Serial No. 46). **Multiple wounds. Extensive bursting fracture of skull, with diffuse cerebral contusion. Subtemporal decompression. Recovery.**

Admission, Aug. 12, 1917, 11 a.m.—No history. Cold and in collapse; stuporous. Resuscitation ward. Became restless: tossing: periods of great activity requiring restraint, alternating with quiet periods. Vomiting: pulse 60.

Wounds.—(1) Multiple lacerated wounds of thigh: (2) Perforating wound of right arm: (3) Small punctured wound of scalp in right parieto-occipital region. *X* rays show massive fracture of skull, with diastasis of sutures (*Fig.* 677).

Neurological Findings, 5 p.m.—Can be roused to restlessness by supra-orbital pressure; apparent paresis of left arm and leg, though he moves all extremities.

Right pupil larger than left. Reflexes all in normal limits. 5.30 p.m.—A Jacksonian seizure, beginning in left face, to arm and leg. Fundi show considerable œdema, with obscuration of cups and nasal margins.

Operation, 6 p.m.—Right subtemporal decompression. Exposure of extensive linear fractures; no bony depression; broken subtemporal plates of bone removed, disclosing very tense, discoloured dura. Dura incised, with partial evacuation of large subdural clot; exposed and protruding brain very tense, and everywhere of a deep cherry-red colour. Closure in layers without drainage.

Post-operative Course.—Became increasingly restless, requiring morphia. Quieted and began to regain consciousness on the 4th day, when he took first nourishment by mouth. Usual wound-healing (*Fig.* 678). By the 12th day he became quite rational, and would obey ordinary commands. Somewhat silly in mental attitude. Persisting weakness of left arm and face, with exaggerated reflexes. By

FIG. 678.—*Case* 113. Subtemporal decompression: wound on tenth day.

time of discharge, Aug. 29 (17th day), was well oriented and in good physical condition, though pulse was somewhat slow and temperature tending to subnormal. No headaches at any time.

Subsequent Reports.—Sept. 1.—Good condition; evacuated to England. Dec. 12, King George Hospital.—Mental state much improved. Discharged permanently unfit. Feb. 22, 1918 (by letter).—At home; inclined to be giddy; refuses to wear his aluminium cap; wishes to get back to the colours. Doubtless shows signs of mental deficiency.

The following case, somewhat similar in character, is of interest in that the patient, having no external wound, was sent down with the diagnosis of 'shell shock.'

Case 114.—Pte. J. P. (Serial No. 66). **Massive fracture of cranium, with cerebral contusion. Decompression. Recovery.**

Admission, Aug. 19, 1917, 12 midnight.—No history obtainable. Unconscious; restless; slight bleeding from left ear; pulse 64.

On examination, no external wound was found; marked œdema and ecchymosis of eyelids. Crepitus elicited by pressure over left side of head. *X* rays show bilateral massive fracture of the skull, with diastasis of fronto-parietal sutures

(cf. *Fig.* 679).* Patient can be roused by supra-orbital pressure ; mutters incoherently ; no evidence of paralysis. Fundi injected, slightly œdematous. Deep reflexes barely obtainable on left : lost on right : normal plantar responses.

Operation, 9 p.m.—Right subtemporal decompression. Linear fractures disclosed, crossing temporal bone. Tense dura opened, showing widespread contusions, with uniform reddish discoloration of brain. Closure.

Post-operative Course.—Began to regain consciousness on 2nd day : after this made very rapid recovery, though mentality was somewhat wandering for several

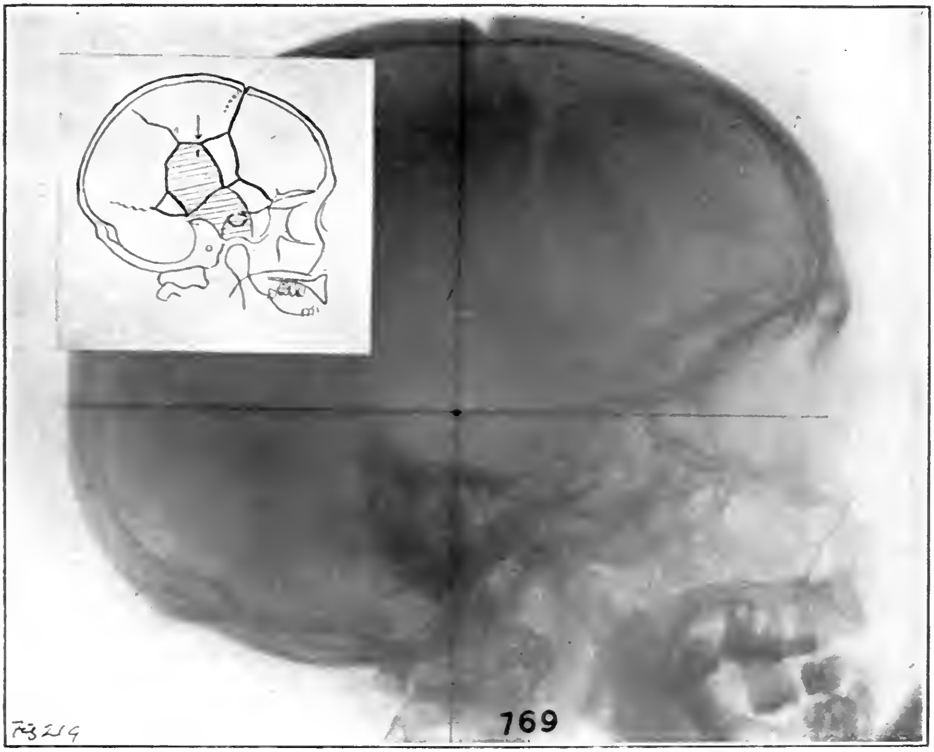


Fig. 679.—*Case* 114. Radiogram tenth day after operation, showing area of decompression. Linear fractures largely obscured : shown in remarque. Silver clip (arrow) on meningeal branch at dural margin.

days. No headaches : usual wound-healing (*Fig.* 680). Temperature and pulse tending towards the subnormal. Evacuated Sept. 2, in excellent condition.

Subsequent Report.—Feb. 15, 1918 (by letter from wife) : Has made a good recovery, though has headaches at times. Is classed B 2 : is with a labour company.

The question might naturally be asked, in cases of this kind, whether, after all, the decompression is essential, and whether *lumbar puncture* might not answer the same purpose, for we are not dealing with a permanent source

* This figure is given to show the x-ray appearance of a silver clip. I have learned of an operation being performed in England to remove one of these clips, under the apprehension that it was a piece of projectile, and doing harm.

of pressure like a tumour, but with a self-limiting process, provided the medulla is not implicated. It is well known that in these conditions of cerebral contusion the brain shows a marked tendency to take up fluids and become œdematous, and oftentimes the cerebrospinal spaces contain an excess of blood-stained fluid —even the subdural space, which under normal conditions contains very little fluid. It has become a matter of common observation that some measure of

FIG. 680.—*Case* 114. Subtemporal decompression : wound on tenth day.

relief can be afforded by the withdrawal of fluid by the lumbar meninges. However, when the brain itself is greatly contused and swollen, the mere withdrawal of 20 or 30 c.c. from the cerebrospinal spaces is but a temporizing measure. This can be well appreciated by observing the effects of a lumbar puncture on a decompressed patient during the early days, when there is protrusion of the tense brain through the defect ; for though the protrusion under the temporal muscle promptly subsides on withdrawing the fluid, the former degree of tension is regained in a very short time, and not infrequently the protrusion seems to return with a higher degree of tension than before. Hence these punctures, even if repeated daily, actually afford but a very brief period of relief.

The operation for a subtemporal decompression is not always easy, and requires experience, facility, and a special type of rongeur forceps, if, without undue injury to temporal muscle, an opening of sufficient size is to be secured. However, there is little doubt but that in many cases a much more prompt return of consciousness is afforded by this measure than would otherwise occur, and in some cases it may be a life-saving procedure.

The following experience affords an illustration of some of these points.

Case 115.—Rfm. L. H. (Serial No. 48).

Aug. 12, 1917.—Admitted unconscious, with the diagnosis of 'concussion'; a small abrasion was present over the right frontal eminence. *X* rays showed a massive fracture of the skull, with fissures radiating from the frontal area.

Patient was admitted in the care of a colleague, who for three successive days performed lumbar punctures, withdrawing as much as 36 c.c. of port-wine-coloured fluid. Consciousness was not regained, and the man continued restless, incontinent, and was at times violent.

On Aug. 15 the pulse became slowed, and he passed into a stupor. He was transferred to us for a subtemporal decompression. On the day following the operation he showed very great improvement; full consciousness returned by the second day; and on Aug. 21 he was evacuated in good condition with practically clear mentality.

Though unfit for further military service, and discharged Nov. 3, he has made a good recovery, barring some tendency to headaches.

The term 'cerebral decompression' is often very loosely used—not to say abused. The mere making of a hole in the skull around a depressed fracture, with wide opening of the dura to relieve pressure of a local contusion or infection, led to many disasters earlier in the war; and it is much better to restrict not only the term, but the procedure, as in the case of tumours, to measures directed toward the relief of pressure carried out in clean fields under temporal or suboccipital muscles, with immediate secure closure of the overlying structures.

At best, however, a subtemporal decompression is not a measure of very wide scope in the cranio-cerebral injuries of warfare, though, as we shall see in the histories to follow, it would have offered two or three of the patients their only chance.

The Fatal Cases.—The five in this group may be briefly recorded.

Case 116.—Pte. C. B. (Serial No. 182).

Lying-out case. Very extensive and infected multiple wounds of back, with fracture of scapula and ribs. Wound of right frontal area, with massive cranial fracture.

Operation.—Temporizing elevation of depressed cranial bone plates; free opening of badly infected extensive wounds of back: Carrel-Dakin treatment. Death from gas infection the following day.

Autopsy.—Extensive fractures of skull: the dura intact: widespread cerebral contusion.

The two following cases were suitable ones for subtemporal decompression, and, had it been possible to determine the side of the large extravasation in each, a chance of recovery might have been afforded, and in the second case the pneumonia possibly forestalled.

Case 117.—A German prisoner (Serial No. 103).

Aug. 16, 1917.—Semi-conscious: massive egg-shell fractures without depression, radiating from the occiput, where is a large infected scalp wound three days old. Attempted local operation under ether, with complete repair and closure by plastic flaps. Wound infected (*B. perfringens*). Death in 24 hours.

Autopsy.—Extensive subdural clot over left hemisphere, the posterior half of which is completely pulped and disorganized to the ventricle.

Case 118.—Pte. F. H. W. (Serial No. 174).

Oct. 5, 1917, 11 p.m.—Irrational: violent: semi-conscious. A ragged wound of vertex. No *x*-ray examination possible.

Operation.—Chloroform. Repair of local wound, disclosing egg-shell fractures without depression; bone removed; dura tense and discoloured; not opened. Lumbar puncture: 30 c.c. bloody fluid. Deglutitory difficulties. Death on 7th day from inhalation pneumonia, with terminal rise in temperature (*Fig.* 681).

Autopsy.—Far-reaching meridional fractures; subdural clot over entire left hemisphere; cerebral contusions; no meningitis. Bilateral bronchopneumonia.

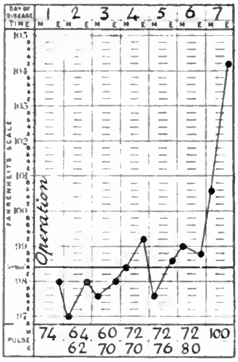


Fig. 681.—Temperature chart of *Case* 118.

Case 119.—Pte. A. M. (Serial No. 100).

Sept. 14, 1917.—No history obtainable; semi-conscious; aphasia; right hemiplegia. Multiple wounds of arm, leg, and head. Massive fracture of skull, with missile embedded in scalp of vertex.

Operation.—Chloroform. Subtemporal decompression, disclosing large subdural clot and contused brain with bleeding vessels. Death on 3rd day from pneumonia, after 24 hours of marked improvement in cerebral symptoms.

Autopsy.—A typical bursting fracture completely encircling skull in coronal plane. Longitudinal-sinus thrombosis; hemispheres widely contused and hæmorrhagic. Bilateral hepatization of both lungs.

Case 120.—Pte. A. L. (Serial No. 197).

Oct. 19, 1917.—Transferred for decompression by a colleague after 48 hours in resuscitation ward. Profoundly unconscious: pulse 110; temperature 103°. Extensive contusions of head and face. Choked disc.

Operation.—Subtemporal decompression: no anæsthesia required. Marked improvement in 24 hours; temperature lower. By 2nd day consciousness partly regained. Bad cough with profuse expectoration; taking nourishment well. On 3rd day pneumonia, with abrupt rise in temperature (*Fig.* 682), and death.

Autopsy.—Brain œdematous and ecchymotic; extensive pulmonary hepatization.

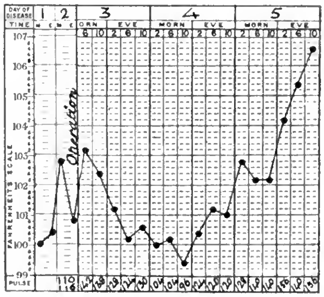


Fig. 682.—Temperature chart of *Case* 120.

It will be noticed that these patients were for the most part refractory, and threatened with respiratory complications due to their compression—a combination which practically prohibits an operation under local anæsthesia with primary morphinization. It is possible that the inhalation narcosis may have had some predisposing effect in the causation of the pneumonia from which three of them died, particularly when one considers how prevalent some form of pulmonary disorder is among the wounded, either as a chronic bronchitis or an irritation from some degree of exposure to gas fumes. The fatalities, however—one of them after a six-days-free interval—bring up another matter on which a caution should be expressed. There is a general tendency on the part of orderlies and nurses who may be unfamiliar with head cases, or uninstructed as regards this particular point, to attempt to feed semi-conscious patients. A typical bronchopneumonia, brought about by misdirected efforts to administer fluids to patients with inactive swallowing reflexes, is a far from uncommon sequel. It is a good rule to keep every stuporous patient in a semi-prone position, and trial feedings should never be first attempted while they are lying on their backs.

THE UNOPERATED CASES.

The record of any series of cases such as constitute the present study would be incomplete without an enumeration of the unoperated cases, with particular reference to the more severely wounded from whom surgical intervention has been withheld. The percentage of such cases must vary considerably according to many circumstances.

It was found from a study of the hospital admission and discharge books for the first fourteen days, including one 48-hour period of considerable pressure, that an average of 50 per cent of all the head cases were immediately cleared after dressing and recording, without being subjected to further examination; and that during the rush period of two days, 85 per cent were thus promptly forwarded to the base. This of course implies that the supposedly more serious cases were alone retained. Whether this is wise from a military standpoint is a matter for others to decide, and customs may change in this respect; but the fact must be taken into consideration in so far as it influences surgical statistics. In slack periods, when no such selection is made, the surgical results for many reasons are much better.

Another factor greatly affecting the character of the wounds and the condition of the cases admitted concerns the bearer parties: the more daring they are and the more quickly the wounded are brought in, the more lives will be saved—but, contradictory as it may seem, the higher will be the hospital death-rate, for more desperately wounded men will reach the casualty clearing station alive than when a corps less energetic and less indifferent to danger is in the field. This applies to cranio-cerebral no less than to abdominal or thoracic wounds.

Then, too, during this particular period of service, with a line of battle advancing and a stationary casualty clearing station, the interval from the reception of the wound to the time of admission became progressively greater, so that fewer of the more immediately serious types of cranial injury survived the average of ten to twelve hours required to bring them in. As an offset to this, those that were brought in were almost certain to have an infection already established. These and other modifying factors must be taken into consideration in judging statistics of any given hospital, in any period, for any particular variety of work.

The 31 cases which, assigned to the writer's team, were not operated upon, fall in three categories:—

1. *Those in which an operation was unnecessary or inadvisable* (11 cases).—An operation may be uncalled for for various reasons. Among the 11 cases, all of which recovered, were 3 examples of extensive cranial fracture without depression, overlain by lacerated scalp wounds too large to close, and whose healing processes could not be expedited by operative measures: such wounds, after being merely scrubbed under local anæsthesia, were Carrelized, and left to heal by the slow process of granulation until they could be skin grafted, and not even were their ragged margins excised. In 2 other cases the unexcised scalp wound was left open owing to infection: one of them was subjected to a secondary craniotomy on reaching the base. There were 3 examples of penetration by a minute missile, with operation

withheld owing to absence of symptoms. There were 3 bursting fractures involving the cranial base, which were treated simply by lumbar puncture.

2. *Those in which operation offered nothing, owing to the extent of the lesion or the patient's general condition* (10 cases).—The 10 cases in which the condition was regarded as hopeless were cases which, if operated upon, would have fallen in *Groups VII, VIII*, or *IX*. There were 2 severely wounded men with a large part of the skull blown away, who quickly succumbed. There were 4 penetrating wounds —one with extreme explosive effect, with elevation of a large cranial gap (*Fig.* 683); the patients survived but a short time. There were 4 examples of extensive bursting fractures, the patients being practically moribund on admission, with advanced pressure phenomena and early respiratory failure.

Fig. 683.—Showing explosive effect of fronto-parietal perforation with elevation of large section of skull.

3. *Those regarded as possibly operable, but in which death occurred before reaching the table* (10 cases).—These cases do not fall in the operation group, though they might have done so had not death intervened. To some, reference has already been made (e.g., *Cases* 3 and 83). The borderline is a very narrow one, and perusal of the fatal cases in the operation series, brief clinical notes of which have been given, will show that desperate chances were often taken to revive cases approaching the terminal stages of compression (e.g., *Case* 78). There is no justification in withholding operation from those unfortunates for whom a prolongation of life would appear to be undesirable; no tribunal is capable of passing such judgement, and unexpected recoveries with unimpaired mental faculties sometimes follow what appear to be the most extensive cerebral injuries.

THE OPERATIVE PROCEDURE.

This has been described in sufficient detail in a recent communication.* As stated, the purpose of the present study is merely to put on record, for the sake of future comparison, the clinical results secured. Some passing comment on these operations in general may, however, not be out of place.

* "Notes on Penetrating Wounds of the Brain," *Brit. Med. Jour.* 1918, Feb. 23.

It is not without interest that early in the war many surgeons who dealt largely with cranial injuries came to advocate the immediate excision and closure of scalp wounds overlying fractures with penetration. They were doubtless forced to this alternative, more because of the unhappy consequences of a fungus cerebri in case the wounds were left open, than through any broad conception of the general principles of primary wound suture, which was then discountenanced.

We are now aware, largely through the pioneer work of French military surgeons, that so far as possible during the few hours before infection takes place, practically all wounds should be given the chance of union by primary suture. The necessity of the most detailed preliminary *débridement* of the wound, as emphasized by Depage, Duval, Le Maitre, and others, before these immediate closures are attempted, is making its way as a matter of fundamental surgical, as well as of military, importance.

These principles apply no less to cranio-cerebral wounds than to those of the extremities; but with the former we are confronted by anatomical difficulties which do not pertain to wounds elsewhere, for in the brain one cannot dissect along the track and lay the part open to inspection as can be done with the majority of wounds in other parts.

The many failures in the past in the primary suture of cranio-cerebral wounds have been due, on the one hand, to the prevailing idea that there was something peculiar about injuries of the nervous system which justified a long delay before operation—a delay which permitted a contaminated wound to become infected; on the other hand, in case the operation was performed in the first few hours after the injury, to imperfect methods of removing—together with other wound débris—the devitalized nervous tissue which makes a favourable soil for bacterial growth.

As generally practised, the cleansing of a contaminated cranio-cerebral lesion has usually consisted in the excision of the scalp wound, piecemeal removal of the bony lesion, enlargement of the dural opening, extraction so far as possible, usually with the insertion of a finger, of the indriven fragments of bone or metal, and closure by sliding or replacing a flap of scalp over the area of the wound. This has been the practice, not only in the early hours when the wound is merely contaminated, but later on when infection has become established.

That 50 per cent of wounds with dural penetration have recovered under these circumstances speaks well for the natural resistance of the brain to mild grades of infection. But if from these past computations the trifling dural punctures like those incorporated in *Group III* had been excluded, and only the cases of actual exposure with contamination of the brain and meninges had been considered, the mortality would in all certainty have been found far higher.

In the technique which has come to be utilized in the later cases in this series, and which is capable, doubtless, of further development in many directions, not only the scalp wound but the contaminated cranial wound as well have been excised *en bloc*. Subsequently, by the aid of alternate irrigation and suction through a soft flexible catheter inserted in the track, the clots and devitalized brain substance are painstakingly removed, the fragments

of bone detected by the catheter are picked out by delicate forceps, and the projectile in as many cases as possible is extracted by the magnet. In short, the same principles of *débridement* utilized so successfully for wounds elsewhere, have in their essentials been adapted to wounds involving the brain.

The criticism has been made that these performances entail too great an expenditure of time and are impossible to carry out in periods of rush; but this is no more true of cerebral wounds than of other deep wounds in which one may wish to secure primary union. In the long run it is far better in an advanced hospital to get one successful primary closure of a penetrating wound of the brain, and to send two others to the base as yet untreated, than to do three incomplete operations in the same period of time, with the probability that all three wounds will break down, and at best undergo subsequently at the base the tedious and uncertain course of secondary wound-healing over an exposed and fungating brain.

There is much difference of opinion as to where these operations should be done, but in view of the fact that the majority of deaths occur from meningitis or encephalitis, it would seem that a forward area is desirable, even should it be admitted that in head wounds infections appear to be slower in taking hold than in the case of lacerated wounds of the muscular extremities.

THE RESULTS IN GENERAL.

As recorded in the opening paragraphs, as our experience increased, the mortality of the 133 wounds with dural penetration was reduced from 54·5 per cent for the first 44 cases, to 28·8 per cent for the 45 cases in the third period—this in spite of the fact that with the advancing line of battle the interval between the reception of the wound and the patient's admission averaged at least six hours longer in the last few weeks of the service. Other factors, in addition to the thorough treatment of the track, doubtless contributed to these improved figures—among them, the routine employment of local anæsthesia, as advocated particularly by Colonel Gray and by De Martel; detailed individual attention to the often complicated post-operative dressings was another element of no little importance.

A tabulation of the 71 fatalities in the operation series taken as a whole, shows that 12 deaths were due to intercurrent causes—to multiple wounds elsewhere, to pneumonia, gas poisoning, and so on; 16 were due to acute intracranial complications—hæmorrhage, extensive lacerations, or compression phenomena arising before the period of sepsis; whereas 43 were due to, or at least associated with, an intracranial infection—meningitis in 14, ventriculitis in 12, encephalitis—usually from gas infection—in 9, and abscess in 8.

Naturally, many of these conditions more or less overlapped: a severely traumatized case might finally die from inhalation pneumonia; an abscess might break into the ventricle; an infection of the brain finally spread both to ventricle and meninges. The figures, however, record the outstanding feature of the post-mortem findings in each case. Their chief significance lies in the overwhelming predominance, even in a forward area, of the infections over all other causes of death; and this would be equally true of wounds of any

other part of the body similarly treated—namely, by closure of the skin over an incompletely cleansed track.

The clinical histories of the 219 operation cases have shown clearly that a large number of the recorded fatalities were avoidable—not only by the employment of a still more perfect technique, but by its more prompt application. The bad repute of cranio-cerebral operations from the standpoint of infection is, without question, largely due to delay—delay in transit, which may be unavoidable; unnecessary delay after admission, which often is avoidable.

So far as our records made it possible, the time intervening between the reception of the injury and the operation has been given with the operative note for each case, and it will have been observed that few were operated upon within the first 12 hours, and many after a 24-hour interval. This means that all of the contaminated wounds had become infected, some most seriously, before they reached the operating table.

The delay in many instances was due to an unnecessarily prolonged sojourn in the ward given over to the resuscitation of the seriously wounded. This period, I think, so far as head cases go, can be eliminated, for the body warmth can be restored and fluids administered during the course of an operation on the head under local anæsthesia, as well as in a special ward. The effects of cerebral contusion are often confused with shock, and the condition of many of these head cases does not improve until trepanation makes possible the evacuation from the intracranial chamber of the clots and pulped brain which are the occasion of pressure symptoms.

Though a period of a year or two must elapse before one can speak of the actual end-results of the 152 cases which were evacuated after operation, the subsequent reports, as may be gathered from the notes appended to the case-histories, have been most encouraging.* The statement has been made that, earlier in the war, 45 per cent of all cases trephined at casualty clearing stations subsequently died at the base: this refers, of course, to a period when cases were forwarded immediately after operation.† In the present series, the more serious cases were retained an average of twelve days, and.

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* The home address of all the patients was taken, and it has been possible by direct correspondence or through Medical Research Committee inquiry cards to trace all of them with the exception of a few colonials. I labour under the impression that most of these cases after reaching England are kept too long in hospitals or convalescent depôts for their best good. In many instances they have been retained apparently for the purpose of bone grafting or of fitting metal plates in the small cranial defect, or for the making of plates of one kind or another which are to be worn in the cap. These measures cannot be of very great service to many of these patients. They should be restricted to the cases with large pulsating defects accompanied by dizziness and discomfort on stooping or exertion.

† Taken as a whole, the mortality for the entire series was 32·4 per cent, or, excluding the 22 scalp wounds, 35·5 per cent. In contrast with these figures for a casualty clearing station, certain figures may be given for cranial operations performed at the base, which at first blush might seem to favour these delayed procedures, did one not realize the elimination which had been taking place in process of transit from the line of battle.

During a nine months' service in two base hospitals with the B.E.F., members of the writer's unit have made careful clinical records of 147 head wounds out of a possible 200 cases—the unrecorded cases having been those of minor nature and without special clinical interest. Of the 147, 34 were scalp wounds, recorded because of concomitant cerebral

as recorded among the fatal cases, only 4 deaths have occurred among the number evacuated, 2 at the base and 2 in home hospitals (*Cases* 17, 59, 66, 76).

The careful studies by Sargent and Holmes of a series of 1239 cases, and by Tuffier and Guillain of a series of 6664 cases which had recovered after trephining, have shown that late sequels, such as epilepsy, insanity, delayed abscess, crippling paralyses, and other residual infirmities, are far less common than had been anticipated. This may serve as an additional source of encouragement for those called upon to operate on these difficult neurological cases.

There is every reason to believe that by earlier operations, and by further improvements in technique along the lines of painstaking aseptic surgery, the accepted high mortality of cases with dural penetration can be very largely cut down; and if this long presentation of a single series of cases can help to bring this about, by serving as a score against which others working under similar conditions may successfully compete, it will have served its purpose.

The writer has received help from many sources in the preparation of this paper, but he is under particular obligation to the Medical Research Committee for permitting Sergeant Maxwell to give time for the making of many of the illus rations. He regrets greatly that he has not had access to the abundant literature on the subject, for this has prevented his making suitable reference to the writings of others who may have made corresponding analyses of a series of cases operated upon under similar circumstances.

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symptoms. Eliminating these scalp wounds, all of which recovered, there remain 113 cases, which fall in *Groups II* to *VI* as follows: *Group II*, 41; *Group III*, 17; *Group IV*, 16; *Group V*, 35; *Group VI*, 4 The more serious types of injury, such as one encounters further forward, were entirely wanting.

Taken together, the total mortality at the base for the 113 cases has been 10·6 per cent: 85 cases had been operated upon before admission, and several had to be re-operated upon for abscess, with 6 fatalities (mortality 7 per cent); 37 *received their primary operation at the base, with only* 6 *fatalities* (*mortality* 16·2 *per cent*), i.e., less than half the mortality percentage of the writer's casualty clearing-station series.

BONE GROWTH AND BONE REPAIR.*

By Professor ARTHUR KEITH, F.R.S.

LECTURE I.

THE FOUNDATION OF OUR KNOWLEDGE OF BONE GROWTH BY DUHAMEL AND HUNTER.

Sometime in the summer of 1736, a calico printer of the City of London entertained to supper John Belchier, a promising young and inquiring surgeon, and, all unwittingly, introduced him at the same time to a method of unravelling some of Nature's greatest secrets. The method to which Belchier was thus introduced was that of vital staining, one which picks out certain elements of the body by distinctive colours while they are still living. The calico printer was an economical man, and used the madder-soaked bran from his dye-vats to feed pigs. The pigs he used to feed his friends. It was a joint of this madder-fed pork which was placed before the young surgeon, then in his thirtieth year and just elected to the staff of Guy's Hospital. It was but natural that a young man, already a fellow of the Royal Society and a contributor to its *Philosophical Transactions*, should have his curiosity aroused by the ruddy colour of the bones of the madder-fed pork, and that he should resolve, on returning to his home, to make further inquiries before bringing this strange matter before the Fellows of the Society. He desired, first of all, to make certain that it was madder and no other substance which stained living bones, and hence he began to feed some of his fowls with madder. One cock, subjected to this treatment—fed by force, for fowls refuse food mixed with madder—died at the end of a sixteen days' course: the bones were stained, even those with the densest structure. Early in the autumn he made a communication to the Royal Society, which was subsequently printed in its *Transactions*.†

Having duly recorded this strange action of madder on bones, Belchier felt that his inquiry was finished, and left the matter there. The man who was to show that Belchier had discovered a means of unravelling the complex manner in which bones grow, was a remarkable French squire—Henri Louis Duhamel, Seigneur du Monceau—but of him more anon. For Belchier there was no problem of bone growth. His master and teacher, the great Cheselden, knew all there was to be known about bones—particularly so far as concerned those of the human skeleton. Bones "are covered by a fine membrane, which upon the skull is called pericranium, elsewhere periosteum. It serves for the muscles to slide easily

* Three lectures of a course on "The Anatomical and Physiological Principles underlying the Treatment of Injuries to Muscles, Joints, and Bones," delivered at the Royal College of Surgeons of England.

† *Phil. Trans.*, vol. xxxix, p. 287.

upon; it is everywhere full of small blood-vessels, which enter the bones for their nourishment." Bones "grow by the continual addition of this ossifying matter; they increase till their hardness resists a further extension; and their hardness always increasing while they are growing, the increase of their growth becomes slower and slower until they cease to grow at all." "In a fractured bone, in which the same kind of matter which ossified the bones at first, is thrown out from the broken ends, there is formed a mass of callous matter."* It is extremely important that we should note these points: that periosteum was a vascular membrane which supplied nourishment; that bones grew like other tissues—by a natural filling up and expansion of every interstice; and that, when broken, the fractured ends threw out a mass of ossific callus. That was the state of knowledge as regards bones when Duhamel and Hunter commenced their investigations.

Our story now shifts from London to France—to the well-managed estate of Monceau, where Duhamel, a confirmed bachelor, and his maiden sister spent busy and studious days. Duhamel belongs to that rare type of man which is represented by Stephen Hales and Benjamin Franklin—men born with a natural aptitude to play the part of detectives amongst Nature's secrets. They wrung them from her by experiment. For Duhamel there was but one sure source of knowledge—observation and experiment. He had spent his youthful days in Paris as a student—a student of law; but he had attended Winslow's lectures, and at an early date had begun investigations relating to agriculture which brought him into touch with the Academy of Science and the foremost researchers of his time. At the age of twenty-seven he was elected a member of the Academy. We make his acquaintance when he was thirty-nine years of age, in 1739, when he made his first communication to the Academy, "Sur une Racine qui Teint les Os en Rouge." He was then living on his estate. A year or two before, Hans Sloane, President of the Royal Society, had drawn his attention to Belchier's paper. His curiosity was aroused, and following his usual custom, he submitted Belchier's observations to the test of experiment. He fed fowls, turkeys, pigeons, and pigs with madder, and found that their bones, and only their bones, were stained red; he noted that only certain parts of the bones were stained, and that the bones of young animals dyed more readily and deeply than those of old animals.

In his communication of 1739 he had really added very little to Belchier's observations. It was merely a preliminary note. His next communication appeared in 1741, and we see he had been hard at work. He had become interested in bones; he knew well how a broken twig became mended, and he wondered how repair was carried out when a bone was broken. He made experiments, and found that the periosteum in the neighbourhood of a fracture became greatly swollen, and served as the chief agent in producing the repairing callus. The lining medullary membrane, or internal periosteum, assisted. By feeding the subjects of his fracture experiments with madder, he could trace the formation of the newly-formed bone, and found that its chief source was the periosteum. He saw nothing to support the prevalent

* *The Anatomy of the Human Body*, by William Cheselden, 6th edition, 1741.

belief that the callus was produced by a 'juice' secreted by the broken ends of bones. He had now realized that the only bone which was stained red was that formed during the period of madder-feeding.

His communications of 1742 and 1743 show us that his further experiments had been attended by a great success. He had discovered an early mistake. If, after giving a course of madder food, and then a course of ordinary food, a pig was killed, he observed in his earlier experiments that nearly all redness had gone from the bones. He was thus led to believe that the stain was only temporary. But on laying such bones open, he observed his mistake—the madder-coloured layer was only covered and hidden by an unstained surface layer, laid down after the madder diet had been suspended. He found, by alternating a madder diet with an ordinary one, that he could obtain alternate red and white rings or layers on the circumference of the bone, the latest-formed layer or plate being on the surface of the bone immediately under the periosteum. Bone therefore grew as wood did—by the super-imposition of layer on layer or plate on plate; and the source of the new layers was the periosteum. The deepest stratum of the periosteum apparently served the same purpose as cambium did for growing wood. In this way Duhamel came to regard periosteum as the maternal tissue of bone; the osteogenetic function of periosteum is Duhamel's discovery.

He was faced by a great puzzle. Bone grew in thickness only by superficial additions laid down lamina upon lamina. He noted that the medullary cavity also kept enlarging as the bone grew: in the pig's tibia the cavity kept increasing until the animal was six months old. He could conceive only one way possible—namely, that as the superficial layers were laid down, there was also an expansion of the shaft-cylinder as a whole, an expansion which enlarged the medullary cavity. He sought to prove the truth of his theory by a new kind of experiment—one he had practised on growing branches. He encircled the shafts of growing bones with rings of silver wire, and in the course of time found, as he expected, that they had cut their way into the medullary cavity. He believed that such a result could be obtained only by an expansion of the shaft. We shall see presently how John Hunter explained the result of such experiments.

Duhamel was familiar with the fact that bench marks cut on the stems of trees maintained a constant level; growth in the trunk did not alter the level. He applied a similar method to bone; he cut 'bench marks' on the shafts of growing bones, by drilling holes at regular and measured distances, inserting within them silver stylets to keep them open. After a definite period he killed the animal, measured the distance between the bench marks, and found they were unaltered; there had been growth in length, but the distance between his marks on the shaft remained the same. Therefore he concluded that all growth in length must take place at the extremities of bones. At what particular part of the extremity, he makes no mention: he observed the epiphyseal lines, but left them unstudied.

Duhamel has been unfortunate in his commentators; with the exception of Flourens, who repeated and extended his experiments in 1842, all have noted his mistakes, and forgotten that he was the man—one not trained to medicine—who discovered that there was a problem of bone growth, and

showed the world how such a problem should be solved. He made the chance observation of an English surgeon into a powerful instrument of research. He showed that bone is stained with madder only as it is being laid down. He showed that a bone grew in thickness by circumferential deposition of plate upon plate: that a long bone grew in length at its extremities; that the deepest layer of the periosteum was the maternal tissue of bone.

Our story now shifts back to London. Duhamel's researches were carried out while John Hunter was spending an untrammelled boyhood on his father's farm at Long Calderwood. But the storm which Duhamel's discoveries had raised was still in full blast when in 1748 Hunter joined his brother's school in Covent Garden at the age of twenty. The great Haller and his pupils had directed a flood of destructive criticism on Duhamel; Haller's name stood high in William Hunter's school: everything he wrote and did received the most respectful attention. If anyone was John Hunter's mentor more than another it was Haller. "How could any anatomist think," said Haller, "that bone is formed only by periosteum?" Why, one had only to look at the lower end of the thigh-bone of a child at birth to see that the theory is untrue; there one could see arteries perforate the epiphyseal cartilage, and at their growing ends see a point of ossification start into being—far removed from the periosteum. In Haller's opinion arteries were the depositors and builders of bone; he believed they could form bone anywhere within the limits of the periosteum. One has only to look at Hunter's preparations, or glance at scattered passages in his writings, to see that it was Haller, not Duhamel, who influenced him. He prepared a series of specimens to show ossific centres forming in the patella, sternum, and metacarpal bones of the calf, and in young epiphyses of human bones. These preparations show us that for him ossification was a function of arteries; ossification, he observed, always broke out at the terminal meshwork of an ingrowing leash of blood-vessels. Haller had repeated Duhamel's madder-feeding experiments, and again studied the repair of fractures, and concluded that the periosteum took no essential part in the formation of the repairing callus—the callus was formed by the broken bone; nor did the periosteum take any part in the formation and growth of bone. In Haller's opinion the periosteum was, as all surgeons then believed, merely a vascular covering to serve for the nourishment of bone. Thus, with the appearance of Haller and Duhamel we have two schools brought into existence—one which regards periosteum as osteogenetic, the true source of bone, and another which regards it as devoid of any bone-forming power whatsoever. After a century and a half of inquiry and discussion we still have these two schools.

To which of the two Hunter belonged there is no shadow of doubt. For him the normal periosteum had no bone-producing power; it was the passive vascular membrane which surrounded and nourished bone. Yet he had seen the periosteum take on an 'ossific disposition' time after time under the most varied conditions of disease and experiment. He believed with Haller—and we shall see the pains he took to verify his belief—that arteries, and only arteries, could form bone, and if periosteum should, under abnormal circumstances, become a site of bone-formation, then that was merely evidence that its arteries could assume a bone-building power.

Hunter was well aware that a fragment of living bone could be detached completely from its periosteum and yet retain its "vital principle" and survive. "In fractures," he said, "adhesion of the detached splinters also takes place . . . and this takes place not only in those which are attached to the soft parts, but even in such as are entirely loose. Therefore these pieces must retain the living principle, and probably only this, while those that remain attached have probably more. I have never examined a compound fracture without finding some of these loose pieces, which shows they must be common. Their union must be similar to that in the transplanting of teeth."* It is clear from the above statement that Hunter knew that isolated fragments of bone could be made to serve as bone grafts. The specimen which he was in the habit of showing at his lectures, to clinch the argument that a large fragment of bone might be detached from its periosteum and yet live, is illustrated in *Fig.* 684. It is a fractured femur, showing a splinter five inches in length which has been so completely detached that its position is reversed: yet it now forms a solid part of the shaft at the point of union.

Fig. 684.—Drawing of the fractured femur which Hunter was in the habit of showing to his class to demonstrate that a large fragment of bone may be detached from its periosteum and yet live and again form a union with the shaft.

We come now to trace the steps which led Hunter to recognize and explore one of the most remarkable of all the powers possessed by living tissues—the power to absorb and remove parts of their substance. The first step occurred in 1754, when he was in his twenty-sixth year and assisting in the management of his brother's anatomical school. He had then commenced his researches on the jaws and teeth, and was struck by the fact that when a tooth was extracted its socket disappeared. Thousands before him must have noted the fact, but they passed it by as self-explanatory. When he came to examine the manner in which milk teeth were shed and permanent teeth came into place, he noted that the roots of the teeth about to be cast out were eroded, and that the sockets in which they were contained were disappearing. He noted also that the last milk molar lay at the root of the ascending ramus of the mandible. But, in the adult jaw, room had been found for the additional three permanent molars between the site of the last milk molar and the ascending ramus. How could such additional

* *Collected Works*, vol. i, p. 502.

dental space be obtained unless the mandible had been remodelled during growth by a dual process of addition and abstraction. He was faced with the same problem when he came to explain how the femur of a newly-born child is transformed into that of the adult. Mere deposition of new bone at the upper epiphyseal line only adds to the upper surface of the neck of the bone. As the femur grows, its neck ought to increase rapidly in depth and breadth, unless deposition on its upper surface is accompanied by a simultaneous process of absorption along its lower surface. It thus became clear to Hunter that, from the infantile to the adult stage in the growth of a thigh-bone, the femoral neck was being continuously remodelled. Growth in bone, he concluded, entailed two distinct processes—one of deposition and one of absorption. That was Hunter's discovery. There was no need to suppose, as Duhamel had done, that the shaft of a bone actually expanded as it grew; the medullary cavity enlarged because, as new bone was deposited on the surface of the shaft, old bone was removed from its interior by absorption.

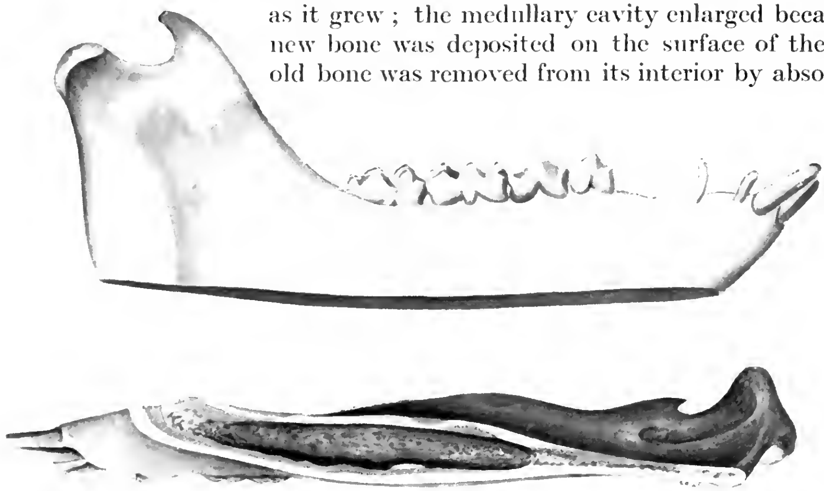

FIG. 685.—Copy of Hunter's drawing to show the manner in which growth takes place in the mandible. The drawings represent two views of the right half of the mandible of a pig, which was fed on a madder diet for a month and then for a month on normal diet. The outline of the ramus at the end of the madder period is shown by the colour. (*Copied by Mr. S. A. Sewell.*)

Soon after Hunter commenced his experimental farm at Earls Court, in 1764, he resorted to Duhamel's method to test the proof of this theory of bone growth. He fed two young pigs on a madder diet for a month; he killed one at the end of the month; the other he kept for an additional month on ordinary food before killing it. Twenty preparations from these two animals are still preserved in the R.C.S. Museum, but the colour has gone. Fortunately, there are preserved accurate 'coloured' life-size drawings of the jaw and femur of the second pig—killed a month after the madder diet had ceased (*Fig.* 685). Hunter found these two bones to answer his expectations in the most exact manner. What had been the condyle and posterior border of the mandible during the madder period were now included in the substance of the ramus—buried by the new condyle and new posterior border which had been added in the non-madder period. From the anterior border of the

ramus the madder-stained bone was almost completely removed by absorption. He found that the thigh-bone (*Fig.* 686) told the same story: what had been the upper surface of the femoral neck during the madder period was now surmounted by new bone, but on the lower aspect of the neck there was no new deposit, but a clear indication of absorption. As the result of his madder-feeding experiments, he concluded that living bone "is constantly changing its matter," and that absorption is as essential a part of bone growth as deposition.

FIG. 686.—Two views of the right femur of the same animal as that from which *Fig.* 685 was taken. The position of the epiphyseal ends at the termination of the madder period is shown.

The recognition that absorption is an essential factor in the process of bone growth brought Hunter face to face with another problem during the youthful years which he spent in his brother's dissecting-room. Bone was laid down by arteries, but by which system of structures was it absorbed and carried into the circulation? At the period he was making his first investigations on the teeth—from 1754 to 1758—his brother William was proclaiming as a new discovery the absorbent function of lymphatic vessels; lymph-vessels were, he said, of the same order as lacteals: therefore they had the power of absorption. In 1758 we find John Hunter instituting experiments to ascertain if veins had the power of absorption, and apparently satisfied when he thought he had proved that they had no such power. There remained only one system of structures which could remove substances from the tissues—the absorbents. "If any solid part of the body undergoes diminution, brought on in consequence of disease, it is the absorbent system that has done it; they are the thieves!"

After having settled to his satisfaction that lymphatic vessels were the agents by which bone was absorbed and modelled, a much more difficult problem presented itself—one which shows us how deeply Hunter sought to pry into Nature's secrets. He saw that the living bone of empty tooth-sockets was removed. He was certain that lymphatic vessels were the agents by which its removal was effected. But what circumstance set the lymphatic vessels to work on the walls of the empty tooth-socket? Why should the living bone of that socket submit? In answering these questions, Hunter seems to offer us a stone rather than bread. "The remote cause of absorption of whole and living parts implies the existence of two conditions, the first of which is a consciousness, in the part to be absorbed, of the unfitness or impossibility of remaining under such circumstances, whatever they may be, and therefore they become ready for removal, and submit to it with ease.

The second is a consciousness of the absorbents of such a state in the parts. Both these concurring they have nothing to do but to fall to work."*

To any one whose imagination has not spanned the wide gulf which separates the simple hydra—Hunter's 'polypus'—from the highly organized tissues of the human body, Hunter's solution of the problem of absorption will sound like one culled from the land of dreams or of metaphysics. But to one who has spanned that gulf, as Hunter had done, and recognizes that every living particle of the human body retains something of that quality of the hydra which we name consciousness, it will be realized that Hunter's answer is a real and true one. In another paper we shall have to examine a law which is applied to explain the manner in which bones shape themselves —Wolff's law—and we shall find that unless the bone-forming and bone-absorbing cells possess just such a property as Hunter ascribed to arteries and absorbents, then such a law is without foundation; yet that law is well founded. No one has given a more vivid or a more accurate description of the manner in which a living bone casts off a dead piece than Hunter. Indeed, it was his study of necrosis and exfoliation that assisted him to realize how important an operation absorption was in the life of bones. I allude to this part of his investigations because we again find him ascribing a consciousness, not this time to the living bone, but to Nature. "Thus, while Nature is busied in getting rid of that part of the bone which is dead, she is laying on additional bone on the outside, the intention of which seems to be that of keeping up the strength of the bone, which would, without this addition, be lessened by the loss of substance. This opinion is, I think, supported by the circumstance seldom occurring in this manner in any bones but those of the lower extremity, which support the animal."† We have here formulated for us one of the chief observations on which Wolff's law is based.

We need not review Hunter's investigations of the processes involved in the healing of fractures, further than to ascertain how nearly his observations agree with those of Duhamel. Hunter regarded the vascularization of the blood-clot effused between the broken ends as the first important stage in the formation of the repairing callus. He saw that the vessels of the callus may be derived from the periosteum, from surrounding torn membranous or muscular tissue, or from the broken ends of the bone. The deposition of bone, he observed, usually commenced at the broken ends, but separate deposits might also occur in the callus. He thus differed altogether from Duhamel, who regarded the uniting callus as a product of the periosteum.

Hunter repeated Duhamel's experiments to prove that a bone could grow in length only at its extremities. He inserted two pellets in the tibia of a young pig; when the tibia was fully grown the pellets remained exactly the same distance apart. *Fig.* 687 shows the shank bones—tarso-metatarsus—of fowls on which he performed similar experiments. One of the specimens is laid open, and reveals two leaden pellets in the medullary cavity—the distance apart being exactly the same as when implanted at an early stage in the growth of the bird. The other shows two canals leading into the medullary cavity. Bristles inserted into these canals show that both are

* *Collected Works*, vol. i, p. 255. † *Ibid.* p. 574.

inclined towards the upper or proximal end of the bone where is situated the main epiphyseal line of growth. Now, when Hunter made the holes, the bone was 71 mm. long and the distance between the holes 42 mm.: when the fowl was killed, the bone was 91 mm. long and the distance between the holes 48 mm. At first sight it looks as if Hunter had proved that there had been an interstitial elongation of the shaft, for the two holes have separated 6 mm. in the course of growth. Hunter has left no interpretation; but I suspect he had fathomed the matter, and realized that he had discovered the cause of the obliquity of the nutrient canals of long bones. The periosteum is firmly fixed to the epiphyseal line at the upper end of the tarso-metatarsal shaft where all growth in length takes place. That growth causes a drag on the periosteum—a drag which decreases in degree as the distal end of the bone is

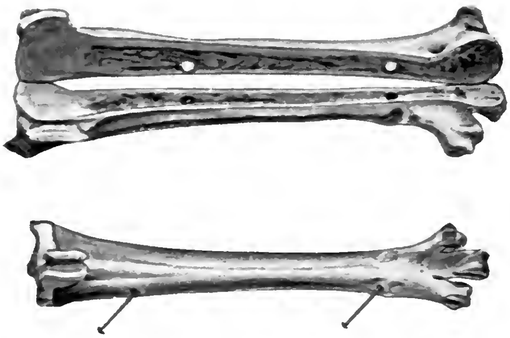

FIG. 687.— Two drawings of Hunterian specimens—both of them tarso-metatarsal bones of fowls on which Hunter experimented.

The upper bone is laid open. The pellets which were inserted in canals of the shaft at an early stage of growth are now in the medulla, but at the same distance apart.

In the lower specimen two pins are inserted in two canals, to show that their direction is oblique. Hunter made two fine holes by a cautery in the shaft during the chick stage. He found the holes had become oblique canals, and that their external mouths had separated several millimetres in the course of growth.

approached. Hence the cauterized holes in the periosteum are dragged, during the growth of the shaft, an unequal degree towards the upper or growing end of the bone, and thus become separated to an increased extent. Sixty years after Hunter's death, Sir George Humphry explained the oblique course of nutrient canals of long bones in the exact manner shown by Hunter's experiment.

The R. C. S. Museum contains a series of specimens which represent one of Hunter's most profitable and illuminating studies of bone growth. The specimens show wonderfully injected sections and preparations of the antlers of the fallow deer at all stages of growth—in their summer velvet covering, in their late autumn condition, and in the state reached in the early spring before they are shed. He realized that Nature has never given more vivid demonstrations of bone growth, never provided such wealth of opportunities for discovering the secrets of necrosis, as in the lavish annual expenditure she makes in providing deer with antlers. No one looking at the rich carpet of arteries which clothes the surface of the rapidly growing bone would fail to conclude, as Hunter did, that arteries are the principal agents in bone formation. We shall see how far the introduction of the microscope, changed our point of view sixty years after Hunter's death. Meantime we note that those two men of the eighteenth century—Duhamel and Hunter—laid the basis of our knowledge as regards the physiology of bone; and of the two, Hunter laid the firmest and deepest part of that foundation.

SHORT NOTES OF RARE OR OBSCURE CASES.

TWO CASES OF STRANGULATED RETROPERITONEAL HERNIA INTO POUCHES IN THE BROAD LIGAMENT.

By C. H. FAGGE, London.

I have failed to find other examples of this lesion, either from a search of available literature or from the experience of friends, though it is not to be expected that similar cases have not been observed. In both instances I was able to convince myself that the bowel was contained in a peritoneal fossa, and had not been forced into connective tissues through a rent in the posterior peritoneal surface of the broad ligament. In the first case the pouch was below the ovarian ligament, and I cannot find any description of any pouch in this position; in the second the pouch was above the ovary and below the tube, where, I gather, a definite fossa is recognized by gynæcologists, though not, as far as I know, described by anatomists.

Case 1.—Mrs. Y., age 61, the mother of five children, was seized with sudden abdominal pain on Dec. 9, 1916, while straining at stool immediately after breakfast. The only history of any accident was a fall downstairs in 1902. Beyond hæmatemesis in 1905, there was no history of any abdominal trouble. The pain was referred to the left iliac region, and she vomited several times; during the day she passed two normal motions. On a second visit, about 4.0 p.m., as pain continued to be acute, Dr. Stilwell decided that it was an abdominal emergency, and admitted her to the Beckenham Cottage Hospital after injecting a quarter of a grain of morphia.

I saw her at 7.0 p.m., when the pain, which had been relieved by the morphia, was beginning to return; her pulse was 108; nothing was to be made out on abdominal examination, except marked tenderness low down in the left iliac region; the tongue was clean; but her aspect was anxious, and in view of the history of agonizing pain, immediate operation was decided upon. No exact diagnosis was attempted before operation; the conditions which were considered as most likely were torsion of an ovarian cyst, strangulated obturator hernia, or mesenteric thrombosis.

When under the anæsthetic, vaginal examination detected a fullness of the left posterior fornix, and rectal examination confirmed the presence of a mass in Douglas's pouch. A left paramedian sub-umbilical incision exposed collapsed small intestine, and lower down and to the right was a coil of ileum which was distended and purple; it could not be drawn out,

and was evidently held down in the pelvis. This and another collapsed coil were traced down to the left side of the pelvis, where they were caught and held tensely as they passed through a small hole in the peritoneum; they were obviously the afferent and efferent coils of the strangulated loop, which could be seen and felt under a layer of peritoneum, filling up the left half of the pelvis. It was at first thought that this orifice was the entrance to the inter-sigmoid fossa, but to the left the peritoneum passed over the pelvic brim, and below its margin was continuous with a tense layer of peritoneum passing on to the side of the uterus. The margin of this opening was now divided with scissors, allowing the distended purple loop of ileum to be withdrawn, when it was found that this loop had passed from behind forwards into the broad ligament, and, filling up Douglas's pouch, had formed the mass which was palpable through the rectum and vagina.

The strangulated coil was covered with hot cloths while the opening in the broad ligament—just below and median to the ovarian ligament—was closed with a continuous catgut suture. The loop actually strangulated was about ten inches long, and above this about two feet or more of ileum were distended and injected. The whole was of good tone and had a shiny peritoneal surface; therefore, as it had only been strangulated some eleven hours, it was judged to be viable and returned to the abdomen, which was closed, with a large rubber drain passed down into Douglas's pouch. Subcutaneous saline had been given throughout the operation, and rectal saline was given during the following night.

The next morning there was considerable abdominal pain, with distention of the lower abdomen; there was no sickness, but much offensive gas was eructated. Water by the mouth and pituitrin were given; she had some sleep after a morphia injection; saline was given per rectum, and on Dec. 11 she had $\frac{1}{60}$ gr. of eserine, after which a good deal of fluid deeply coloured with blood was passed per rectum. Eructation now ceased, and several loose motions were passed during the next two days. Recovery was only prejudiced by a mild bronchopneumonia on the sixth day.

In February, 1917, she had another attack of severe left-sided abdominal pain, and this recurred in March; she was admitted to Guy's Hospital, where an x-ray examination after a bismuth meal gave no definite evidence. On March 12 the abdomen was again opened, and extensive adhesions between the scar and the lower ileum were freed: the hole in the left broad ligament was still closed. In January, 1918, Dr. Stilwell reported that the patient remained well.

Case 2.—Miss P., age 49, was seized with abdominal pain at 2.0 a.m. on Nov. 30, 1917; she vomited at intervals, and her bowels acted twice. Dr. Mowll saw her on the morning of Dec. 1, when she did not appear acutely ill; her pulse-rate and temperature were normal; she continued to vomit occasionally, and the pain was not severe. On the next day she was not so well, and fainted. On Dec. 3 she still vomited occasionally, and the pain, located to the middle of the abdomen, was severe; there was now slight rigidity and tenderness over the right rectus slightly internal to McBurney's point. Dr. Mowll diagnosed appendicitis, and admitted her to Surbiton

Cottage Hospital, where an enema was given with no result; her pulse was then 86, and her temperature slightly raised.

When I saw her, at 7.0 p.m. on Dec. 3, her pulse-rate had risen to 100; the physical signs were unaltered since the morning, and did not suggest a grave abdominal condition. The history of the attack and the location of the pain to the right iliac fossa naturally led Dr. Mowll to the diagnosis of acute appendicitis, with which I candidly agreed; the point of chief tenderness was perhaps more than usually median, but this might have been occasioned by an inflamed appendix hanging over the pelvic brim.

A free right paramedian incision exposed a healthy appendix; the small intestine was slightly distended, and there was an abnormal amount of clear fluid in the peritoneal cavity; on passing the hand into the right side of the pelvis, a coil of the lower ileum was found to be fixed to the back of the right broad ligament. Further exposure, with traction, showed a blue cyst-like body in the substance of the ligament to the back of which the loop of ileum led. After the experience of the first case, I recognized the condition present, and, defining the upper crescentic margin of the orifice, I cut it with scissors, releasing about two inches of ileum, congested but shiny, and with anæmic rings at the two ends where constriction had been caused by the margin of the ring; it had just the usual appearance of a similar coil released from a strangulated femoral hernia. I could now demonstrate that the pouch into which it had passed was above the ovary and its ligament; and, as by the division of its neck it had been converted from a saccular pouch into a shallow fossa incapable of encouraging a similar retroperitoneal hernia, I did not think its obliteration by suture necessary. The abdomen was closed without drainage.

The patient made an uninterrupted recovery, and left the hospital on the sixteenth day. She has remained well since.

REVIEWS AND NOTICES OF BOOKS.

Troubles Locomoteurs consecutifs aux Plaies de Guerre. By AUG. BROCA. Small 8vo. Pp. 155. 1918. Paris: Masson et Cie. 4 fr. net.

PROFESSOR BROCA deals with his subject from the pathological aspect, basing the proper treatment of ankylosed and stiff joints upon the appreciation of the exact anatomical or pathological obstruction to movement. He also defines ankylosis as the stiffness which results after the original injury or inflammation has subsided, pointing out that too often the stiffness is treated at a stage when the treatment ought really to be directed to the cure of the inflammation. Not seldom these two points are forgotten by the enthusiastic surgeon or by his masseur: by the former because he does not think in terms of pathology; by the latter because he is ignorant and has not received adequate instruction from the surgeon. If Professor Broca's book is read sufficiently widely to correct these faults, he will have done good work.

In the main the advice and opinions expressed will be found to be in agreement with those of the best known English orthopædic surgeons. For example, the chosen positions for fixation of the various joints are similar to those adopted in this country, and the principles of the use of mobilization will find general acceptance; so also will the author's general condemnation of the wide early excisions so often done in war surgery, which leave flail joints with such a poor functional result. Perhaps, however, Broca esteems a little too lightly the results attained by operative measures such as arthroplasty and tendon transplantation, which have found considerable favour in this country. The book can certainly be recommended to all who have to deal with the late results of war wounds, and who have to solve the problem of making good the functional utility of the damaged limb.

The Collected Papers of the Mayo Clinic. Vol. VIII, 1916. Edited by MRS. MELLISH. Large 8vo. Pp. 1014, with 411 illustrations. 1917. London and Philadelphia: W. B. Saunders Co. $6.50 net.

AN endeavour to discover in this volume any new line of thought or any departure from the beaten track which might distinguish it from its predecessors, led to a momentary joy upon the discovery of a short article by Beckman on spinal-cord tumours, of which he reports eighteen cases. This sensation was speedily destroyed by the discovery of an obituary notice of its author, which pays just tribute to his sound decision in difficulty and to his capacity for work. Several years ago we had an opportunity of watching Dr. Beckman when in charge of the 4th Surgical Theatre at Rochester, and were much struck by the delicacy and precision of his technique in deep dissections of the neck, and also by the scientific bent of his mind. His death, the result of an acute infection acting on a delicate physique already damaged by much physical and nervous wear and tear at high speed, will be a great loss to the personnel of the Clinic.

The main value of this publication rests upon its statistical worth as a record of a vast number of cases of certain ailments, excellently observed under scientific conditions, and most ably treated: dealing with such large numbers, the common errors of statistics are correspondingly diminished; moreover, the reports emanate from men who, working together, become so experienced that the personal factor is less likely to lead to false opinions and deductions. Thus, in comparing the relative mortalities of cholecystectomy and cholecystostomy, Dr. Charles Mayo has available 2493 examples of the former and 2854 of the latter operation, performed by the staff of the Clinic within nine years.

There are again in this, as in former volumes, numerous papers upon ulceration of the stomach and duodenum, upon disease of the gall-bladder, and upon goitre, none of which show appreciable advance upon similar papers in former volumes.

Drs. William and Charles Mayo contribute two very similar papers upon the treatment of cancer of the rectum, for which 430 patients have been treated by radical operations; opinion is evidently now inclining towards the abdomino-perineal operation in suitable cases; and its division into two or three stages is advocated.

Dr. Samuel Robinson, in a long paper, deals very thoroughly with the surgery of bronchiectasis; the pathological conditions found in this disease are considered in detail, and, having reviewed the different lines of medical treatment unfavourably, the author advocates some type of radical operation; this is divided into two or three stages.

Dr. Henderson's article upon derangements of the knee-joint is largely a *résumé* of the writings of English surgeons; these injuries must be relatively rare in the States, and surgeons there obviously do not enjoy the clinical experience on which Rutherford Morison and Martin of Newcastle have founded their well-known writings: there is no reference to the type of injury which Morison designated 'bucket-handle fracture,' and the author does not seem to have appreciated the fact, which appears to us fundamental, that the disability is always due to a fracture and not to a complete displacement of one of the menisci.

We have drawn attention before, to the drawings which always adorn these volumes; those in this number are no less beautiful and no less well chosen than others which have appeared in previous years, and their reproduction results in a work of art for which both the artist and publisher deserve the reader's thanks.

Découverte des Vaisseaux Profonds par des Voies d'Accès Larges (Exposure of the Deep Vessels by Free Incisions). By J. Fiolle and J. Delmas. 1918. Paris: Masson & Cie. 5 fr.

M. Pierre Duval writes a short preface in which the aim of the authors is outlined. The volume itself, of some 120 pages, has at first sight somewhat the appearance of a guide to methods in use in an operative surgery class; yet it is really based on personal practical experience on the French front. The authors have discovered, or at least put on paper, a fact of practical value with which any surgeon with experience at a casualty clearing station will agree—viz., that under the conditions of injury which exist, a very free incision is required for the adequate exposure and determination of extent of injury of the deep vessels. When we have given them credit for this point, there is very little else in this volume to recommend it, save the obviously practical and careful methods advocated. The median calf incision for exposure of the posterior tibial vessels and nerve—perhaps the most troublesome of any in actual casualty-clearing-station practice—is now widely used in the British Imperial clearing stations; the description of this operation is admirable, and will well repay reading by those who anticipate work of this kind. Another sound chapter is that which deals with the method of access to the large vessels at the base of the neck, though the possibility of injury to the thoracic duct has evidently not struck the authors, for no mention is made of this structure beyond the remark that it is exposed in the field of operation on the left side. There is no clear reason why no chapters are devoted to the deep femoral, or to any of the iliac vessels, unless it be that the methods in common use are regarded by the authors as adequate; this is certainly not the case with the deep femoral vessels, and the reviewer would have thought that no vessel in the body would better repay the writing of a chapter—comprising both theoretical investigation on the cadaver and practical experience on the living—on the best method of access to this vessel; for anyone who has had to deal with wounds which may have involved this vessel or its branches will agree that they set no mean problem to the surgeon.

The great defect in practical teaching and disadvantage in actual practice, which this volume cannot eliminate, concerns the fact that the surgeon in dealing with the wounds of war cannot in most cases choose his incision for himself; its line is fixed by the wounds of entry and exit, and by the track of the projectile; these must be excised, and only in exceptional cases will a fresh incision to deal with vascular complications be justifiable.

Ambulance de "l'Océan," La Panne. Fasc. 1, July, 1917. Large 8vo. Illustrated. Paris: Masson & Cie. 30 fr.

Dr. Depage in this, the first, volume promises to issue every six months a similar one giving an account of the work of the different departments of his field hospital founded near the end of 1914. Those who have had the opportunity of visiting both the excellent main hospital and the advanced abdominal station established opposite Dixmude in June, 1916, will agree that excellent material should exist to sustain the interest in these publications during the War, and will congratulate the editors upon their happy thought in analyzing their experience and in detailing their methods for the education of the Medical Services of the Allies. A large portion of this volume is occupied by an account of the establishment and its organization; the remainder is filled by papers, chiefly clinical, upon the cases already treated and the methods in vogue.

An abundantly illustrated article by Professor Debaisieux on the early treatment of wounds gives a full description of the problems which arise and of the factors upon which the value of primary excision and Carrel's disinfection depends: this leads naturally to a chapter by Dr. Lagasse on the secondary suture of wounds, in which excellent photographs show what can be done by rigidly adhering to the indications afforded by Carrel's bacterial count. Similarly satisfactory results are available for the inspection of all medical visitors to the Ambulance.

A third noticeable paper is by Dr. Janssen on wounds of the skull and brain; much space is devoted to the consideration of the morbid anatomy of these wounds: the principles guiding treatment and the methods adopted do not differ from those in practice in the British Medical Service.

We shall look forward with interest to the succeeding volumes, and trust that the articles dealing with the department for the manufacture of artificial limbs will do justice to the ingenuity and skill of those who have organized and who administer this branch.

Memoranda on Army General Hospital Administration. By Various Authors. Edited by P. Mitchell, M.D. (Aberdeen), Lieut.-Colonel R.A.M.C. (T.) Demy 8vo. Pp. vi + 109, with 10 illustrations. 1917. London: Baillière, Tindall & Cox. 5s. net.

The Army Medical Service has grown by slow degrees to its present state, and in its growth has acquired by a process of accretion many cumbrous methods and administrative faults, the result of a long peace, a small army, and few sick. Civil hospitals have laboured under similar defects, but a wholesome atmosphere of criticism, coupled with the necessity for self-preservation owing to the fact that they were unendowed, have simplified the methods and cured many of the defects. One of the great and lasting advantages which the Army Medical Service will gain from the present war is the dilution of the regular service with civilian practitioners, many of them with great administrative experience. These men, being bred up in a freer atmosphere and approaching their work untrammelled by service conditions, see how the various problems can be solved without necessarily taking the line of least resistance. From the advances that have already been made, it seems clear that the solutions offered are carefully considered by the military authorities, and in many cases adopted. This is the right spirit in which to work, and by so doing our Army Medical Service will gain an even higher position than it now holds in the estimation of the public.

Colonel Mitchell, the officer commanding No. 48 General Hospital in Salonica, writes the articles in this volume on "The Officers," "The Co-ordination of the Civil and Military Medical Demands during a prolonged War," "The Nursing Service," and "Kitchens and Cooks." He commits the consideration of "The Medical Service" to Major A. W. Falconer; "The Surgical Service" to Major G. H. Colt; "Camp Sanitation" to Captain Robert Richards, and "The Quartermaster's Duties" to Lieutenant S. Taylor. The articles written by Colonel Mitchell and Major Colt are especially worthy of consideration. Some of the suggestions are certain to meet with whole-hearted approval. Examples are the abolition of the present extraordinarily cumbrous system of diet sheets, which would not be tolerated for a moment in any civil hospital, and of the employment of highly skilled and trained medical

officers upon work which could be equally well done by a clerk. Other suggestions are more difficult to carry out in actual practice, as that of grading and utilizing medical officers according to their aptitudes; whilst others again are inadvisable, as in alternating officers for short periods at home and abroad. Major Colt devotes a portion of his article to the production of a 'wall card' designed to act as a diet sheet, medical case-sheet, temperature chart, and transfer certificate. A step in this direction has already been taken by the War Office, but Major Colt's card is more elaborated than that at present in use.

Genito-Urinary Surgery and Venereal Diseases (White and Martin). By Edward Martin, A.M., M.D., B. A. Thomas, A.M., M.D., and S. W. Moorhead, M.D. Pp. 929, with 422 engravings and 21 coloured plates. Tenth edition. Large 8vo. 1917. Philadelphia and London: J. B. Lippincott & Co. 30s. net.

A new edition of this volume is particularly welcome at the present time, when the establishment of venereal clinics throughout the country is really materializing, and when it becomes more necessary than ever for the practitioner to add further to his knowledge of the subject.

All genito-urinary diseases—medical and surgical, affecting male and female, young and old—are gone into fully. The general scheme is excellent, and not only is treatment given in detail, but pathology takes its deservedly prominent place. A notable feature is the sanity of the views expressed throughout the book; it is essentially practical, while the simple language in which it is written is admirable. New ground covered, or old material revised, includes vaccine and serum therapy; tests for renal function; destruction of vesical new growths by high-frequency dessication; the laboratory diagnosis of syphilis and control of treatment; and the treatment of the enlarged prostate. The coloured plates illustrating syphilitic skin lesions, and the treatment of the various venereal diseases, are particularly good, while a large coloured plate is most helpful to the better understanding of the Wassermann technique.

We cannot agree that the best instrument for the diagnosis of a stricture is a bougie or urethrometer; these may be useful in some cases, but a diagnosis of urethral stricture should always be made with the urethroscope. Nor can we agree with the method advocated for the opening of a prostatic abscess, for when so treated an incurable fistula frequently persists; this risk can only be avoided by draining the abscess into the prostatic urethra, approach being obtained by opening the urethra just in front of the prostate gland.

For the next edition we suggest the incorporation of diagrams which will illustrate the anatomy and embryology of each area as it is dealt with; these would be most useful to a busy practitioner, who probably has only short periods of time at his disposal for reading. A few clerical errors are to be noticed in the text, doubtless due to war conditions. The illustrations and plates are profuse, and a good detailed index adds considerably to the value of the volume. This readable book is a leading work upon its subject, and can be thoroughly recommended.

Le Péritoine en Chirurgie de Guerre. Etude Clinique. By M. Stassen and J. Voncken. 8vo. Pp. 168, illustrated. 1917. Paris: Baillière et Fils.

This book is a record of clinical and pathological observations founded on experience of abdominal wounds at an advanced operating centre behind the Belgian lines. Though it contains little that is new to those who have been called upon to do similar work with our own armies, yet it is a most admirable exposition of the present state of abdominal surgery under modern conditions of warfare. To secure the best results in these cases, transport of patients must be reduced to a minimum by having the stations within a short distance (two or three kilometres) of the line, and operations must necessarily be carried out in surroundings which are somewhat crude, and under conditions which make scientific observation difficult. Nevertheless, the book is a striking record of surgical success in a field which at the commencement of the war was thought to be barren.

Difficulties of diagnosis dominate the whole picture, and necessitate the provision

of these special units where every case which has a possible penetrating wound of the abdomen may be sent for observation by a specially skilled staff. Formal diagnosis is rarely possible, for by the time that the classic symptoms of perforation present themselves the most favourable moment for operation has passed.

Penetrating wounds of the upper third of the thigh, the buttocks, perineum, and lower thorax are all suspicious.

The 'false abdomen,' penetrating wounds with hæmorrhage only, and penetrating wounds which flood the abdomen with intestinal contents, may all present the same initial symptoms. Cases of extraperitoneal injury only—the 'false abdomen'—especially if accompanied by severe hæmorrhage, as from the kidney or by damage to the osseous pelvis, may give rise to any or all of the symptoms of peritoneal shock ; at the same time, multiple lacerations of the intestinal wall may cause so little local or general disturbance that a false sense of security is engendered. Though no one symptom can be considered diagnostic of perforation, it may be said that a general board-like hardness of the abdomen, persistence of shock in spite of measures taken to combat it, a rising pulse, and bad facies, present a syndrome which when present is rarely at fault as pointing to perforation ; whilst consideration of the probable path of the missile, radiography, and the reaction of the patient under conditions of warmth and rest, are helpful—but occasionally misleading—aids to diagnosis.

These difficulties in diagnosis have led the authors to the same conclusion as that formed by most surgeons, that is, to explore when in doubt. Exploratory laparotomy may be performed through a very small incision, when the presence of blood, gas, or other foreign matter should lead to an enlargement of the wound and a thorough overhaul of the whole peritoneal cavity. On the other hand, in some cases they prefer a dissection out of the track of the missile, layer by layer, till it is clear by actual demonstration that it has or has not penetrated the peritoneum. On the whole this latter course does not appeal to us, for it does not absolutely exclude intraperitoneal visceral injury by impact without penetration: we prefer this *débridement* to be done as a secondary operation, after laparotomy has demonstrated unmistakably the presence or not of intraperitoneal injury. This criticism, however, is on a minor point of operative technique in a book devoted almost entirely to clinical and pathological observations, for which we have nothing but praise.

The Surgical Operations on President Cleveland in 1893. By W. W. Keen, M.D., LL.D. Pp. 52. 12mo. Philadelphia : George W. Jacobs & Co.

This is an interesting excursion along a bypath of medical history, by a veteran surgeon who took a leading part in the adventure. Professor Keen—who, doubtless in consequence of the war, is now described as a Major in the Medical Reserve Corps, United States Army—tells for the first time the story of the operations performed upon President Cleveland for malignant disease of the superior maxilla in July, 1893. The United States was passing through so grave a crisis at the time that it was described afterwards as "the most deeply-seated financial storm in the history of the country." It was thought, and, as the event proved, thought correctly, that "Mr. Cleveland is about all that stands between this country and absolute disaster, and his death would be a great calamity." Had his influence been removed, even temporarily, the wrecking party would have been in the majority and the panic would have become uncontrollable. It was of the utmost importance, therefore, that the illness of the President and the performance of a serious surgical operation should be kept a profound secret. The ubiquity of the press and the restless energy of the reporters made concealment difficult, but Professor Keen describes the steps by which the operation was accomplished on board the yacht *Oneida* whilst she steamed at half speed up the East River. Dr. Bryant, of New York, was the actual operator, Professor Keen assisted, and Dr. Hasbrouck, a dentist, gave the anæsthetic. The operation was performed on July 1 : on July 5 the President walked ashore ; and on Aug. 5 he opened Congress, without anyone suspecting what had occurred. He survived the operation until 1908.

The story is admirably told, and gives a lively picture of the means taken to outwit the press. The book is daintily produced, and is a credit to the publishers.

EDITORIAL NOTICE.

The shortage and increased price of paper make it necessary to effect some economy in the issue of the next volume. So far as can now be seen, this will not involve raising the price or curtailing the matter; but will be brought about by using a slightly smaller type and setting it closer, and by giving smaller margins. In this way each number, whilst consisting of about 150 pages as compared with 200 in former volumes, will represent the same amount of material, both letterpress and illustrations.

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